USE OF MARGINAL COST FACTORS BY SHIP DESIGNERS AND COMPONENT DESIGNERS

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BY

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ABSTRACT

Marginal weight factors for predicting the impact of equipment or ship feature changes on the full load displacement of a baseline ship design have been previously developed. The use of these factors has not yet gained widespread support because the assumptions upon which the marginal weight factor concept is based have not been fully validated and there is some doubt as to the universality of the factors for different types of equipments and ship features.

The mechanics of using the marginal weight factor concept are explained and the assumptions of the concept validated by relating them to the computerized ship synthesis models by which the factors are generated. It is found that existing marginal weight factors are valid for most equipment types other than electronics and a method of adapting them to use with electronics equipments is developed.

Detailed procedures for determining values of the equipment parameters necessary for use with marginal weight factors are developed based on the logic of the synthesis models and four examples of the use of marginal weight factors to determine equipment impacts on a baseline ship are given.

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I INTRODUCTION

A. Marginal Cost Factors

The term "marginal cost" can be defined as the cost of one additional unit of some commodity at a specified level. In a production operation, marginal cost might refer to the cost of producing the 901st unit of the product when the production level is at 900 units. In ship design, marginal cost refers to the "cost" of an additional unit of some design parameter which affects the overall design; for example, an additional crew member or an additional ton of payload weight.

In evaluating the cost of adding an equipment or subsystem to an existing ship design, the term "cost" can take on any of several different meanings. It should always include the acquisition and installation cost of the equipment and the cost of "sizing" the ship to accomodate the equipment, but might be expressed as the change in ship acquisition cost, life cycle cost, cost in terms of ship performance degradation (e.g. decrease in ship speed), or cost in terms of increase in full load displacement.

The importance of including the cost of sizing a ship to accommodate an equipment in the overall cost of the equipment was addressed by Graham in Reference 1. Subsystem designers historically have not had the knowledge necessary to evaluate the ship sizing cost of an equipment

addition because the ability to make this evaluation requires a knowledge of naval architecture and a skilled ship design capability. In an attempt to provide a method of determining overall ship impacts of equipment additions, marginal cost factors have been developed which provide subsystem designers, as well as ship designers, with the tools necessary to make this evaluation.

It has been found that the "cost" of adding an equipment to an established ship design can be evaluated with reasonable accuracy by summing the "cost" of four design parameters of the equipment; weight, space, electrical, and manning requirements. The "cost" of each of these parameter additions can be found by multiplying the parameter requirement by a marginal "cost" per unit requirement of the parameter. The "cost" per additional unit is the marginal "cost" factor.

This thesis addresses the "cost" of equipment additions in terms of their effect on the ship's full load displacement (that is, the change in full load displacement due to the addition of the equipment to the design). The term "marginal weight factor" (MWF) will, therefore, be used instead of "marginal cost factor" when referring to the change in full load displacement associated with a unit change in one of the four basic design parameters above.

B. Application of Marginal Weight Factors

There are three groups of designers who can make use of marginal weight factors.

First, subsystem designers can use marginal weight factors as a logical basis for evaluating the ship system impact of a given subsystem design and, more importantly, for designing subsystems which will have minimum impact on the ship system. Subsystem designers presently use acquisition cost, installation cost, or operating cost, or a combination of these three costs, as a basis for selection of subsystem designs. Marginal weight factors can provide the subsystem designer with the tools necessary to evaluate the <u>true</u> impact of a given subsystem on the ship. More importantly, MWF's can provide him with a means of trading off subsystem parameter requirements in the early stages of subsystem design in order to arrive at a minimum ship impact subsystem as a final product.

Second, designers who are responsible for specifying design standards and design criteria can use MWF's to evaluate the ship system impact of these standards and criteria. As an example, consider the habitability standard specification of living space required per crew member. Using a marginal weight factor for space, the designer can determine the ship system impact of setting

the living space requirements at different levels and can use this information in trade-off studies being conducted to decide the space requirement.

Third, ship design managers can use MWF's to get quick "back of the envelope" estimates of subsystem or design standard/criteria impacts on the ship system in order to cross-check impact studies presented to them by subsystem designers or vendors. They can also use MWF's as a basis for answering ship impact questions from higher authority when time does not permit an in-depth engineering study of the question at hand.

C. Previous Work

The first systematic generation and use of marginal cost factors was by James Sejd, a naval architect in the Advanced Ship Development Programs Office of the Naval Sea Systems Command (ex-Naval Ship Systems Command). Sejd used one of the Naval Ship Engineering Center's (NAVSEC) computerized ship systhesis models, known as DD07, in conjunction with a weight-based cost model to develop marginal cost factors for use in impact studies conducted during the design of the Navy's newest frigate (FFG-7). Sejd presented the results of his study at the 11th Annual Symposium of the Association of Senior Engineers in a paper entitled "Marginal Cost - a Tool in Designing to Cost".

More recently, Howell, in Reference 2, developed marginal weight factors for three different baseline ships in order to study the relationship of the marginal weight factors to ship size and type. The three baseline ships were a 3,500 ton frigate, a 6,000 ton destroyer, and an 11,000 ton cruiser. These three baseline ships were similar to actual recent ship designs or design studies. Howell's marginal weight factors were generated using the same systhesis model that Sejd used (DD07). Once the baseline ships were established, parameter variations about these baselines were conducted by varying the input data. The parameters which were varied were:

1. Manning, varied in increments of four men to totals of plus and minus twenty crew for the smaller ships with an additional set of ten men increments (out to plus and minus thirty crew) for the large ships.

2. Electric load requirements, varied by plus and minus 1000 kilowatts for most of the ships with some linearity checks at intermediate levels of plus and minus 100, 300, 500 and 800 kilowatts.

3. Weight, varied by addition to, and subtraction from, armament weight in increments of fifty tons. This process was conducted at three vertical locations:

a. Twenty feet below the main deck

b. At the main deck, and

c. Forty feet above the main deck.

The ranges of weight variations for the three baseline ships were:

a. For the frigate, minus 50 tons to plus 150 tons

b. For the destroyer, minus 150 tons to plus 250 tons, and

c. For the cruiser, minus 250 tons to plus 250 tons.

4. Space, varied in increments of 500 square feet to values of plus and minus 2500 square feet for all three baseline ships.

The effects of these parameter variations on baseline ship full load displacement were then plotted versus the parameter variations and curves fitted to the data. The slopes of these curves are the marginal weight factors - the change in full load displacement associated with a unit change in the parameter level.

The results of Howell's study were somewhat inconclusive as far as the relationship of the MWF's to ship displacement was concerned because he found that the MWF's depended more on ship geometry than displacement. However, Howell additionally attempted to demonstrate the validity of the marginal weight factor concept by comparing MWF predictions of ship full load displacement changes associated with a series of equipment additions to

synthesis model predictions of the same effects. He found that his MWF's, generated by varying armament inputs into the model, predicted equipment impacts to within seven percent of the model prediction for armament equipments and small electronics equipments, but the predictions for larger electronics items did not compare favorably with the model predictions.

In spite of the poor predictions for larger electronics equipments, Howell concluded that the marginal weight factor concept is a valid technique for evaluating equipment impacts and that the marginal weight factors developed by him are valid for armament and mechanical equipments as well as small electronics equipments. He further concluded that the four support requirement MWF's needed for equipment evaluation are those for weight, space, electrical power, and manning. In addition, Howell recommended the development of MWF's for large electronics systems and the development of an engineering procedure, or "cookbook", for the application of marginal weight factors.

D. Purpose of Thesis

The purposes of this thesis are as follows:

1. To validate the assumptions of the marginal weight factor concept and identify limitations on its use. The validation of assumptions will be based on a

comparison of the marginal weight factor technique of predicting equipment impacts with the synthesis model and manual techniques of accomplishing equipment impact predictions.

2. To develop detailed procedures for using marginal weight factors. These procedures will be specifically tailored for use with MWF's generated by the DD07 synthesis model, but should be easily adaptable to MWF's from any other model. The procedures should also serve as a guide for determining equipment support parameters for use as inputs to synthesis models in a consistent manner.

3. To identify a method of adapting existing MWF's to use with equipments for which Howell obtained poor prediction results.

E. Organization of Thesis

The remaining portion of this thesis is organized as described in the following paragraphs.

Chapter II describes the mechanics of using the marginal weight factor concept and lists the assumptions made in the concept. These assumptions are addressed and validated by relating them to the ship synthesis model design process used to generate marginal weight factors. The chapter concludes that all of the assumptions are

valid but some alterations to the MWF process will be called for in the case of non-linear MWF plots and for certain types of equipments.

Chapter III gives detailed procedures for determining the weight, space, electrical, and manning requirements of equipment or ship feature changes for use with marginal weight factors. These procedures can also be used to standardize the method of arriving at equipment support parameters used as fixed data input to synthesis models.

Chapter IV describes a method for adapting existing armament-input-generated marginal weight factors to use with electronics systems.

Chapter V contains the author's conslusions on the work conducted for this thesis and recommendations for further work.

II MECHANICS, ASSUMPTIONS, AND LIMITATIONS OF MARGINAL WEIGHT FACTORS

This chapter explains the mechanics of using the marginal weight factor concept and lists the assumptions made in the concept. These assumptions are then addressed and validated by relating them to the ship synthesis model design process by which marginal weight factors are generated. It is found that the assumptions are generally valid, but that some limitations on the use of the concept do exist. These limitations, however, are found not to be highly restrictive on the use of the marginal weight factors.

A. Mechanics of the Marginal Weight Factor Concept

Mechanically, the use of marginal weight factors is a simple procedure. Once a baseline ship's marginal weight factors have been established, the user needs only to determine values for four support parameters of the equipment being evaluated, multiply the values of these parameters by their respective MWF's, and sum the products to find the total impact of the equipment on the baseline ship's displacement. The four equipment support parameters are: the direct equipment weight (W) in tons, the direct equipment space requirement (S) in square feet, the direct equipment electrical requirement (E) in kilowatts, and the direct equipment manning requirement (M) in number of men. Detailed procedures for determining these four support parameters are contained in Chapter III of this thesis. The marginal weight factors for these four support parameters are: the marginal weight factor for weight (MWF_W) in tons per ton, the marginal weight factor for space (MWF_S) in tons per square foot, the marginal weight factor for electricity (MWF_E) in tons per kilowatt, and the marginal weight factor for manning (MWF_M) in tons per man. The product of the value of a support parameter and its corresponding marginal weight factor is always expressed in units of tons. This product is the impact

of the particular equipment support parameter on the full load weight of the baseline ship. These impacts will be denoted by the letter "I" with a subscript corresponding to the support parameter (i.e. I_W, I_S, etc.). The sum of these individual support parameter impacts is the total baseline ship weight impact, I_{TOT}, in tons, of the equipment. The process looks like this:

$$W \text{ (tons)} \times MWF_W \text{ (tons/ton)} = I_W \text{ (tons)}$$

$$S \text{ (ft}^2\text{)} \times MWF_S \text{ (tons/ft}^2\text{)} = I_S \text{ (tons)}$$

$$E \text{ (kw)} \times MWF_E \text{ (tons/kw)} = I_E \text{ (tons)}$$

$$M \text{ (men)} \times MWF_M \text{ (tons/man)} = I_M \text{ (tons)}$$

$$I_W + I_S + I_E + I_M = I_{TOT} \text{ (tons).}$$

As straightforward as this concept seems, implicit in it are several assumptions, the validity of which is not immediately clear. These assumptions are as follows:

1. That the summation of individual parameter impacts to find total equipment impact is valid.

2. That marginal weight factors take into account both direct and indirect effects of the equipment addition.

3. That the marginal weight factors are valid and constant for the values (range) of equipment direct support parameters.

4. That the marginal weight factors are valid for the equipment type or ship feature being evaluated.

5. That the four parameters, W, S, E and M, adequately describe the equipment's impact on the ship.

These assumptions of the marginal weight factor concept will be addressed in Section C of this chapter. The discussion in that section will be based on the design sequence and naval architectural calculation procedures of the synthesis models used to generate marginal weight factors. It will therefore be necessary first, in Section B, to consider the models themselves, and particularly the DD07 model from which the MWF's under consideration were generated.

B. Ship Synthesis Models

1. Introduction

The discussion and description of ship synthesis models in this section is condensed from References 2, 3, and 4.

Mills, in Reference 3, defined a ship synthesis model as, "an engineering design procedure for converting a set of performance requirements into the physical description of a ship which can satisfy those requirements". A synthesis model differs from standard naval architectural calculations in that at the start of the first stage of design there is no definition of the ship at

all - it begins with a blank sheet of paper. Standard naval architectural calculations are engineering procedures for testing the adequacy of the ship, one aspect at a time, provided a design exists to be examined. A model also differs from the later stages of design in that it produces a much less detailed physical definition of the ship. A vastly more detailed description is required to build a ship than is needed to make an initial estimate of its size and cost.

Ship synthesis models are used by naval engineers to conduct feasibility studies, estimates of the ship system level physical characteristics and cost related data for a design which represents a feasible solution to a specific set of performance requirements. Two of the uses of these feasibility studies are (1) to conduct engineering subsystem trade-off studies, and (2) to evaluate changes in standards and practices. In the former use, the results of detailed alternative subsystem studies made outside the synthesis model are summarized in the form of the weight/location, space, energy, and manning requirements for each competing subsystem, and each in turn is input into a feasibility study in lieu of the subsystem on which the model was based, and the impacts on ship size and cost compared. In the latter use, feasibility studies are used, in a

manner similar to that just described for subsystem trade-offs, to assess the ship system level impact of changes to the standards and practices on which engineering studies are based.

By their nature and use, very large numbers of feasibility studies are required. As a consequence, shortcut estimating techniques are employed in their preparation with emphasis being placed on relative accuracy among the studies. Examples of these shortcut techniques will become apparent in the following discussion on model synthesis processes in the next subsection.

Since the model is given no design with which to begin, one must be synthesized. This is done by assuming the necessary ship characteristics, making calculations to check the adequacy of these assumptions, and then revising them until all requisite tests can be simultaneously satisfied without further modification. In short, an iterative procedure is used. The synthesis model performs calculations to satisfy, simultaneously, the following conditions before a solution to the design is considered to have been reached:

a. Energy available equals energy required.

b. Internal space available equals internal space required.

c. Displacement equals weight (Archimedes' Principle).

d. The distribution of weight and volume is such as to satisfy arbitrary criteria for transverse stability, girder strength, and seakeeping.

The methods by which DD07 satisfies these four conditions are discussed in the next two subsections. Most existing surface ship synthesis models use logic similar to that of DD07 so the following subsections are equally applicable to other models of this type.

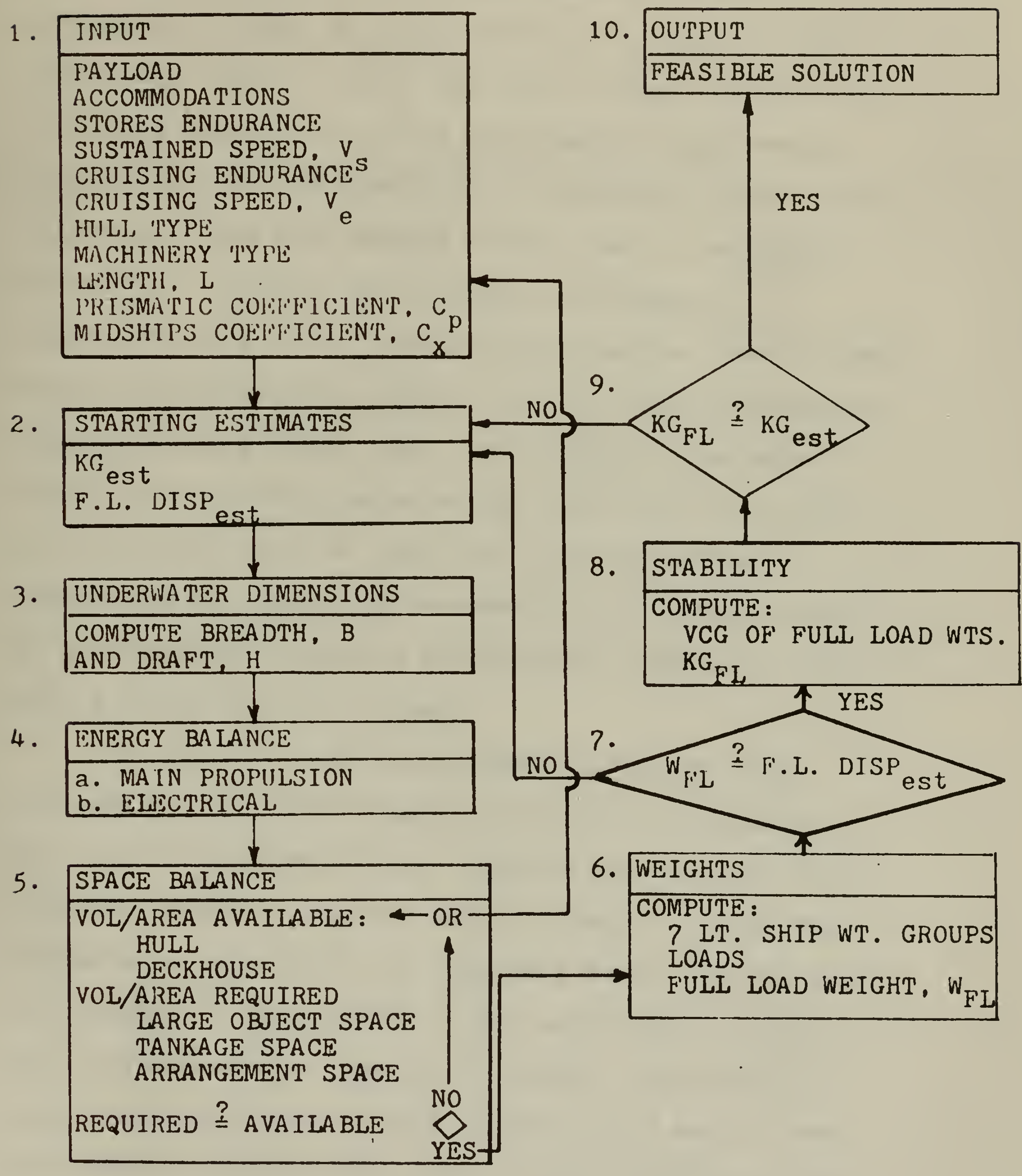
2. General Synthesis Procedure

A simplified macro flow diagram of the major steps in the DD07 design approach is shown in Figure II-1. Some procedures of the model have been omitted from this flow diagram in order to present it as simply as possible and because they do not affect the present discussion. As can be seen in the diagram, the design approach is an iterative procedure with iterations being conducted at three major points in the program; first, on the available volume/area; second, on the full load weight; and third, on the stability (KG). The purposes of these iterations will become evident in subsequent discussions.

Within the program it is necessary to estimate the physical characteristics (weight, space, location, and energy requirements) of the ship subsystems. These estimates are made in two different ways. First, for the propulsion and electrical subsystems, estimates of

FIGURE II-1

SIMPLIFIED MACRO FLOW DIAGRAM OF MAJOR STEPS IN DD07 DESIGN APPROACH



physical characteristics are based on estimates of subsystem demand. That is, the size of the propulsion subsystem is based on a calculation of required shaft horsepower (SHP) to drive the ship through the water at the speed called for in the performance requirements, and the size of the electrical subsystem is based on the electrical load (KW) demand of the rest of the ship's subsystems. Second, the estimates of physical characteristics of all other subsystems are based on ship system characteristics such as a full load displacement, length, manning level, etc. For example, the area required for living spaces within the hull of the ship is considered to be an empirical function of ship length and the number of accommodations, and the weight of the lighting system is an empirical function of the ship's total enclosed volume.

As shown in the flow diagram, using the input information, the model computes "starting" estimates of full load displacement (F.L. DISPL.) and the associated vertical center of gravity (KG) in Step 2. Using these estimates coupled with the program's stability criterion, the breadth, B, and draft, H, are calculated in Step 3. With the underwater dimensions defined, the sustained speed horsepower requirement is calculated and is used to establish the size and power of the propulsion plant

in Step 4. Also in Step 4 the size and disposition of the electric plant is computed based on payload and personnel electric load inputs, propulsion plant power and the present definition of the ship's size.

The sizes of the propulsion and electric plants are used in Step 5 to establish the size of the machinery box which in turn is used to calculate the size of the hull. The size of the deckhouse is then established as a function of the hull size, and the volume/area <u>available</u> in the combination of the hull and deckhouse computed. It is important to note here that there are three general "types" of spaces required on a ship. First, "large object space" is required for large items such as main propulsion machinery and some large armament items. Second, "tankage space" is required for storage of liquids, and, third, "arrangement space" is required for the living and operating functions of the ship. Large object space can be converted to either tankage or arrangement space, and arrangement space can be converted to tankage space. The reverse processes, however, are not possible. It therefore follows that the requirements for each "type" of space must be satisfied independently. In calculating the volume/area <u>available</u> in the hull and deckhouse, the model first computes total ship volume and subtracts the volume of the machinery box from this

total. The remaining volume is available for either arrangement or tankage. An empirical relationship is used to determine how much of this volume is usable for tankage only and how much may be used for either arrangement or tankage. The volume/area requirements for the machinery box, tankage, and arrangement area are next estimated. The tankage requirement is based on calculations of tankage volume required for fuel oil, reserve feed water, potable water and aviation fuel. The total arrangement area requirement is the sum of estimates of area requirements for four functional categories which will be given and defined in the next subsection. Once the available and required volumes/areas are estimated the two are compared and reductions in deckhouse size, or increases in hull depth are made as necessary to establish a balance between required and available volume/area.

Modern surface combatant ships are volume limited - that is, area/volume requirements are the dominant factors in setting their size. Step 5 in the synthesis procedure is, therefore, the most critical step and is the "heart" of the process.

After this "volumetric sizing" of the ship has been accomplished, an estimate is made for the weight of the ship and its loads in Step 6. In Step 7, this full

load weight is compared to the starting estimate of full load displacement. If a match within a predetermined tolerance (normally 2 tons) is achieved, the program proceeds to Step 8. If the desired match is not attained, the present estimate of full load weight becomes the displacement estimate for the next cycle and the complete process outlined above is repeated. This procedure is repeated until default or closure is achieved.

Once the weight/displacement balance is settled, vertical centers of gravity for the weights are estimated, and a comparison of the computed value of KG_{FL} with the "starting" estimate of KG is made. In a manner analogous to that described above for weights, the program cycles until closures for both weight/displacement and KG_{EST}/KG_{FL} are simultaneously achieved. At this point, a feasible solution is considered to have been attained.

3. Accomplishment of Major Design Tasks

This subsection addresses the synthesis model's methods of accomplishing the four major design tasks necessary for a solution to the ship definition problem. As mentioned in Subsection 1 of this section, these major design tasks are the energy balance, the space balance, the weight/displacement balance, and the stability balance. These tasks are Steps 4, 5, 6 & 7, and, 8 & 9, respectively, on the macro flow diagram of Figure II-1.

The discussion will be limited to a general description of the model's methods and will not go into details of specific estimating relationships used by the model. The portions of the discussion related to the space and weight/displacement balances are more detailed than is necessary for an understanding of the assumptions section (Section C) of this chapter, but have been made so in order to provide a basis for understanding some of the detailed procedures for determining equipment support parameters in Chapter III. Material particularly pertinent to the reader's understanding of the assumptions section will be denoted by (*) and material particularly pertinent to Chapter III will be denoted by (#).

a. <u>Energy Balance, Step 4</u>

(1) The size of the propulsion plant is determined by calculating the required SHP which must be installed in order to satisfy the sustained speed requirement. This calculation is performed by an automated version of the Taylor Standard Series. The SHP required for cruising speed is also calculated here for the purpose of calculating the amount of endurance fuel required to meet specified cruising range.

(2) The number and capacity of the ship service generators is determined by the value of the ship service functional electric load. The value of this

ship service functional load is the sum of electronics and armament functional load (*) and the power requirements of propulsion auxiliaries, steering gear, air conditioning, and ventilation, firepumps, other machinery and deck auxiliaries, and hotel services. The electronics and armament functional loads are obtained by summing the electrical requirements input as part of "payload" information. The power requirements of the remaining subsystems are obtained by empirical relationships with ship system characteristics, other subsystem characteristics, and input information.

b. Space Balance, Step 5

The purpose of this step is to determine the ship size necessary to satisfy the functional area and volume requirements for the design. Since the ship envelope which is being defined is comprised of the hull and deckhouse, the problem expands to the determination of the size of each.

The size of the hull is determined by the values of L, B, H, C_p and a weather deck shear line which is established to satisfy, simultaneously, the following conditions:

(1) Adequate machinery box depth

(2) Adequate hull girder depth at mid length

(3) Adequate freeboard forward and aft

(4) Reasonable values of deck shear

(5) Continuity of the uppermost full length deck

The size (volume) of the deckhouse is estimated as a function of ship length, L.

Once the size of the hull has been determined, the total volume within this hull is found by adding the hull volume below the water (HVBW) and the hull volume above the water (HVAW). HVBW is precisely defined by the following equation: $HVBW = L \times B \times H \times C_p \times C_x$. HVAW is approximated by the following equation: $HVAW = L \times B \times C_{wp} \times F_{av} \times f$. Where C_{wp} is the waterplane coefficient, F_{av} is the average freeboard, and f is a "flare factor".

The machinery box volume is next calculated from machinery box length (which was found in an earlier machinery box sizing routine not shown in Figure II-1), cross-sectional area of the machinery box, and prismatic coefficient of the machinery box.

Tankage volume is calculated by subtracting the machinery box volume from the total hull volume and using the empirical relationship referred to in the General Synthesis Procedure subsection to determine how much of the remaining hull volume is usable for tankage. This empirical relationship is a function of ship depth at mid-length, C_p, C_x, and the ratio of machinery box length to ship length.

Arrangement volume in the hull is then found by subtracting machinery box volume and tankage volume from total hull volume. This arrangement volume is then converted into arrangement area using an empirical relationship of arrangement area to arrangement volume.

As mentioned above, the volume of the deckhouse is estimated as a function of length, L. Because of the geometric regularity of the deckhouse, it is assumed that deckhouse area can be related to deckhouse volume by a simple "average deck height". A value of 9.0 feet is routinely used. All of this deckhouse area is assumed to be arrangement area.

Total arrangement area is the sum of the arrangement area in the hull and arrangement area in the deckhouse.

At this point, the available machinery box volume, available tankage volume, and available arrangement areas are known.

The required tankage volume is obtained by multiplying previously calculated weights of fuel oil, reserve feed water, potable water, and aviation fuel by appropriate factors for density, expansion, tail pipe allowance, and structure. In addition, an allowance for peak tanks, cofferdams, and voids is made.

The total required arrangement area is the sum of the area requirements in the following four functional categories:

(1) "Payload" (A_1)

(2) "Living" (A_2)

(3) "Stores" (A_3)

(4) "Ship" (A_4)

The definition of, and method of calculating, required arrangement area in each of these four categories follows.

Required "Payload" Arrangement Area (A_1)

This requirement is obtained primarily from a summation of the individual area requirements for the electronics and armament systems specified in the input data. A further allowance is made for payload storerooms, maintenance space and other support requirements not exclusively devoted to an individual system but shared by several systems by multiplying electronics and armament space inputs by factors of 1.23 and 1.15 respectively. (*) (#)

Required "Living" Arrangement Area (A_2)

"Living" spaces include berthing, messing, sanitary, administrative, commissary, medical, personnel services (laundry, barber shop, ship stores, etc.) and recreation spaces. A_2 is estimated as an empirical function of ship length and the number of accommodations. (#)

Required "Stores" Arrangement Area (A_3)

"Stores" spaces include dry, chilled, and frozen provisions and GSM stores. A_3 is estimated as an empirical function of the number of accommodations and the required length of stores period, in days, for each kind of stores as specified in the input.

Required "Ship" Arrangement Area (A_4)

"Ship" spaces are spaces which are needed because the ship is a vehicle which must be propelled and controlled. The main machinery box requirements and tankage portions of this category have already been accounted for. However, provisions must be made for steering gear, anchor handling, air intakes and uptakes, shaft alleys, etc. Also, the ship provides supports for other functions carried in the ship. These support spaces include ventilation fan rooms, air conditioning, compressor, and pump rooms. These support spaces plus storerooms and maintenance spaces for hull and machinery and all access trunks and passageways are included in the "ship" category. A_4 is estimated as a function of the ship's cubic number $(\frac{LBD}{100})$. (#)

As mentioned above, the total required arrangement area is the sum of A_1, A_2, A_3, and A_4. (*)

At this point, the available and required machinery

box volumes, tankage volumes, and arrangement areas are known. The available and required machinery box volume match, of course, because the available is derived from the required within the routine. The available and required tankage volumes and arrangement areas are compared and, if necessary, changes in the hull and deckhouse sizes made to balance the available with the required. This balancing is performed within the Space Balance, Step 5, or if necessary, by returning to Step 1 and increasing length.

c. Weight/Displacement Balance, Steps 6 and 7

Once the sizes of the hull and deckhouse have been established, it is possible to make weight estimates for the remaining components of light ship and loads. The light ship weight consists of the seven major weight groups of the "Weight Classification for Ships of the United States Navy", 1955 (BSCI Weight Classification System). The loads weight includes the weight of the ship's complement, provisions, stores, liquids, ammunition, and aircraft. The seven light ship weight groups and the general method of calculating their weights are as follows:

Group 1, Hull Structure

(1) Hull, determined as a function of the ship's cubic number

(2) Deckhouse, determined as a function of deckhouse volume

(3) Foundations, determined as functions of equipment weights (#).

(4) Masts and king posts, assumed to be a constant 25 tons

(5) Sonar dome, specified in the input data

Group 2, Propulsion Machinery

(1) Basic propulsion machinery, determined by the type of propulsion plant and the number of propellers and SHP

(2) Shafting, bearings, and propellers, determined by number of shafts, SHP, saft RPM, and ship draft and length

Group 3, Electrical Plant

(1) Electric power generation equipment, estimated in Step 4 as a function of electrical load

(2) Power distribution switchboards, an empirical function of electric plant capacity (#)

(3) Power distribution cable, an empirical function of electric plant capacity and ship length (#)

(4) Lighting system, an empirical function of total enclosed volume (#)

(5) Electric plant repair parts, a constant value of 4 tons (#)

Group 4, Communication and Control

(1) Armament control systems, summed from input information

(2) Electronic Systems, summed from input information

(3) Other Group 4 equipment, including navigational systems, interior communications systems, non-electronic countermeasures, and spare parts (#), an empirical function of the ship's cubic number

Group 5, Auxiliary Systems

(1) "Basic" auxiliary systems, a function of total enclosed volume in the ship (#)

(2) Auxiliary steam, exhaust steam, and steam drains, a function of installed propulsion power.

(3) Roll stabilization system, obtained from input information

Group 6, Outfit and Furnishings

(1) Hull fittings, boats, boat stowage and handling, ladders and grating, non-structural bulkheads and doors, painting, deck covering, hull insulation and work-shop equipment (#), an empirical function of the ship's total enclosed volume

(2) Equipments in commissary and other utility spaces, and the furnishings for living, office, medical, and dental spaces, an empirical function of the number of accommodations

Group 7, Armament

The total weight of Group 7 is obtained by summing the weights of input armament items.

The load weights are calculated as follows:

(1) Complement - based on the number of accommodations

(2) Provisions and stores - based on the number of accommodations and stores endurance period

(3) Potable water - based on the number of accommodations

(4) Reserve feed water, lube oil, and endurance fuel - all previously calculated based on SHP, endurance, electrical load, and hotel steam requirements (#)

(5) Water in the sonar dome - based on the type of sonar specified in the input information

(6) Ammunition, aircraft, and aircraft fuel - all obtained from input data (#)

Once the light ship weight and loads weight have been calculated, they are added to find the full load weight of the ship. (*) This full load weight is then compared to the starting estimate of full load displacement. If the two balance, the program continues to the stability balance. If they do not balance (within the specified tolerance), the computed full load weight replaces the previous value of estimated full load displacement and the entire design cycle begins again at Step 2. (This is the second major iterative step in the design process. The first was within the space balance routine). (*) This process is repeated until the computed full load weight and the estimated full load displacement balance.

d. <u>Stability Balance, Steps 8 and 9</u>

The purpose of this task is to estimate the vertical center of gravity of the design in the full load condition

(KG_{FL}). This is done by estimating a vertical center of gravity (VCG) above the baseline for each of the weight entries estimated in the weight/displacement balance. The VCG's of some input items are expressed as distances from reference points other than the baseline but these are converted within the program to distances from the baseline. (#) The moment for each weight entry is obtained as a product of each weight and its associated lever. The moments are summed, and divided by the full load weight. The result is the estimated KG_{FL} in the full load condition. The vertical centers of gravity of the weight entries are estimated either by empirical functions obtained by studying a number of existing designs, or from input information.

After the vertical center of gravity for the entire ship in the full load condition (KG_{FL}) has been calculated, it is compared to the initial estimate of vertical center of gravity (KG_{EST}). If these values do not agree within a specified tolerance (presently 0.1 feet), then the value of KG_{EST} is replaced by KG_{FL} and the entire design cycle begins again at Step 2. This is the third major iterative step in the design process. (*) This process is repeated until a balance between KG_{EST} and KG_{FL} is obtained.

Once a balance between KG_{EST} and KG_{FL} is obtained, the design cycle is regarded as being complete.

C. Assumptions of the Marginal Weight Factor Concept

In order to address the validity of the assumptions listed in Section A of this chapter, it is necessary to discuss how MWF's are developed and their relationship to the computerized ship synthesis models used to develop them.

First, a baseline ship is designed by the synthesis model. Once this baseline ship is established, parameter variations about the baseline are conducted by varying the payload input data and the input manning level. The payload support parameters varied are the payload weight, space requirements, and electrical requirements. Each of these four parameters is varied individually in order to analyze the effect of each separately. The range of parameter variations is normally carried out as far in the plus and minus directions as is felt necessary to cover the range of design changes which one might want to analyze using MWF's. Since the vertical location of a weight has a great deal to do with its impact on a ship (the higher the weight, the more pronounced is the effect on ship stability), weight variations are usually carried out in at least three different vertical locations in order to determine the effect of vertical location on the marginal weight factor for weight.

The effect of each parameter variation on ship full

load displacement is tabulated and the tabulated values plotted on graphs of change in full load displacement versus change in support parameter. One of these plots will look like Figure II-2, although it might not be linear as is the one in this figure. Non-linear plots will be discussed later in this section. The slopes of lines fitted to the data points on these plots are, by definition, marginal weight factors - the change in full load displacement associated with a unit change in the support parameter.

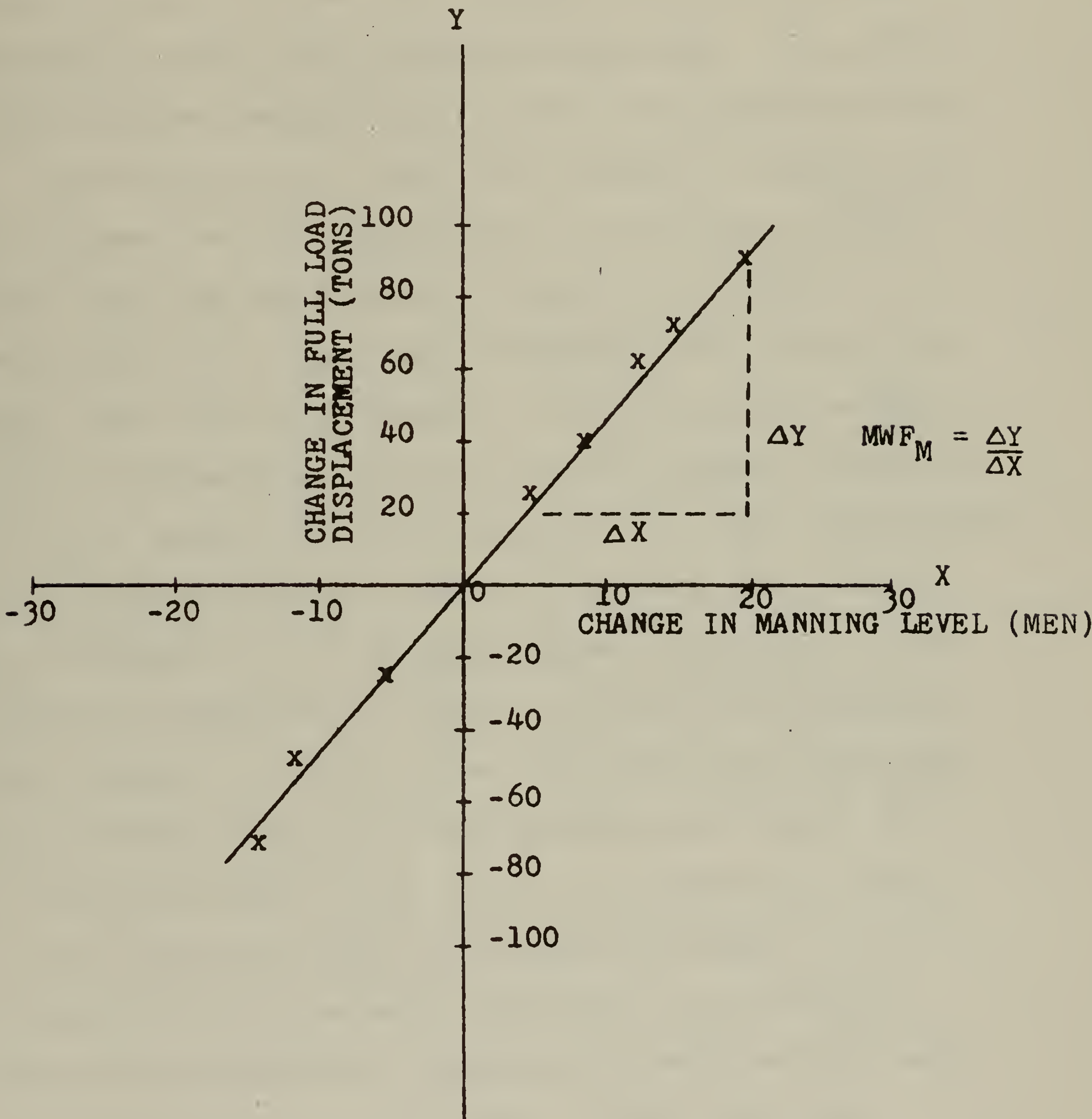
Each of the assumptions in Section A will now be addressed individually.

Assumption 1. The summation of individual parameter impacts to find total equipment impact is valid.

From the above description of the method of developing MWF's, and Figure II-2, it is apparent that multiplying one equipment support parameter by its corresponding MWF yields the impact of that parameter on full load displacement, for this is merely reversing the process by which the MWF's were developed in the first place (e.g. $MWF_M = \frac{I_M}{M}$, $\therefore I_M = M \times MWF_M$). Assumption 1 is that summing these individual impacts gives the total impact. To validate this assumption, the manner in which the parameter changes affect the design process is inspected. In this inspection it will be assumed that an equipment is

FIGURE II-2

TYPICAL MARGINAL WEIGHT FACTOR CURVE FOR MANNING LEVEL PARAMETER VARIATIONS



being added to the ship, but the discussion would be equally applicable to equipment removals with the changes taking place in the negative, rather than positive, direction. It must be kept in mind that changes to an established, feasible baseline ship are being considered. The effect of the equipment weight addition will be considered first.

Referring to the macro flow diagram in Figure II-1, the equipment weight addition can be considered to be first "seen" by the program in Step 6, the weight computation, as it adds payload weights into one of the seven light ship weight groups. This additional weight creates an imbalance in Step 7 and the program recycles to Step 2, where the old estimate of full load displacement is replaced by the new calculation of full load weight. This increase in F.L. $DISPL_{EST}$ causes an increase in the underwater dimensions, B and H, on which the propulsive power depends. In Step 4, the main propulsion machinery size increases because of the increase in B and H, and the electrical plant size, which is a function of ship size and propulsion plant size, also increases. The increased size of the main propulsion and electrical plants creates additional demands for machinery box size and tankage space for additional liquids, while the increase in the ship size creates additional demands for "ship" arrangement space. These increased demands are

satisfied by increasing the volume/area available in Step 5. In Step 6, all light ship weight groups, as well as the loads, increase in weight because of the previous increases in ship and subsystem sizes. These increases cause another weight/displacement imbalance in Step 7 and the entire cycle is iterated until a new feasible solution is obtained. The difference in the full load displacement of this new feasible solution and that of the baseline ship is the impact of the equipment weight addition.

The effects of equipment electrical, space, and manning requirements would trace through the design process in the same manner as the equipment weight addition with the only difference being that they would first be "seen" by the program in Steps 5, 4, and 1 respectively. The final effect of each parameter change on the baseline ships displacement is the same regardless of whether or not other parameter changes have been entered into the program at the same time.

In the final iteration through the synthesis model design process, the weights of the seven light ship weight groups and the loads are estimated in Step 6. At this point, the effects of all parameter changes on each weight group and loads weight have been taken into account. The model then adds these weight groups and loads to get full load displacement. The MWF procedure, on the other hand,

is contrived to calculate the effect that each individual parameter change has on all weight groups and loads first and then add these changes, by parameter, to get the change in full load displacement. Figure II-3 illustrates the comparison between the model method of summing parameter effects and the MWF method of performing the same task. In this figure, the columns are the parameters varied and the rows are the weight groups. The numbers are hypothetical changes in each weight group weight due to the parameter variation at the top of the column. The synthesis model would, in effect, add the weight changes across each row and sum these subtotals down the side to get the total ship weight change (see the arrows labeled "Synthesis Model"). The MWF procedure adds the weight changes down the columns first and then sums these subtotals across the bottom to get the total change (see the arrows labeled "MWF"). In either case, the total effect is the same, therefore Assumption 1 is valid.

As a practical example of the validity of Assumption 1 for this thesis, a series of computer runs was made using a synthesis model which uses the same basic design logic as the one described in Section B of this chapter, with a typical destroyer-type ship as a baseline. A hypothetical equipment with the following direct support requirements was conceived:

PARAMETER

WEIGHT GROUP	W	S	E	M	Synthesis Model
1	2.80	1.74	0.75	7.35	12.64
2	0.75	0.10	-	-	0.85
3	-	0.06	3.35	-	3.41
4	-	0.10	-	-	0.10
5	0.36	0.52	-	2.10	2.98
6	-	0.26	-	2.55	2.81
7	6.30	-	-	-	6.30
Loads	0.63	0.18	0.25	1.80	2.86
MWF	10.84	2.96	4.35	13.80	31.95

PARAMETER EFFECTS BY WEIGHT GROUP

FIGURE II - 3

Weight	20 tons
Space	400 square feet
Electrical load	200 kilowatts
Manning	5 men

Six computer runs were made. The first was the baseline destroyer; the second, the baseline destroyer with payload weight increased by 20 tons; the third, the baseline destroyer with the payload space increased by 400 square feet; etc. Finally, the sixth run was the baseline destroyer with all of the hypothetical equipment's direct support parameter requirements added at once. The full load displacement of the baseline destroyer was then subtracted from the full load displacement of each of the other five ships to find out what weight increases were caused by the additions of the equipment's direct requirements. The details of this example will be given in the discussion of the next assumption, but it suffices as far as Assumption 1 is concerned to say that the total of the increases caused by each parameter change entered individually was equal to the increase caused by entering all parameter changes simultaneously. This is a practical validation of Assumption 1.

<u>Assumption 2.</u> The marginal weight factors take into account both direct and indirect effects of the equipment addition.

Table II-1 is a compilation of the weight effects found in the specific example cited in the discussion of Assumption 1. For each of the six ships the weight of each of the seven light ship weight groups, loads, and full load displacement is shown along with what change that weight represents over the baseline ship.

Consider, first, Ship #2, the baseline ship, with an additional 20 tons of armament payload weight. If indirect effects of this weight addition were not taken into account, the only weight group which would show an increase over the baseline weight would be Group 7. As can be seen from the figures, however, Weight Groups 1, 2, 4, 5, and loads also showed increases to make the full load displacement increase by 27.3 tons instead of just the 20 tons of additional armament weight. The origin of the extra 7.3 tons can be traced by considering the effects caused by adding the 20 tons of payload. The payload weight increase causes the full load displacement to increase, which requires more shaft horsepower to achieve required speed. The effect of the additional SHP shows up in the Group 2 weight and in the load weight because of additional fuel required. The Group 1 weight increases because of the additional machinery box and tankage volume required and because a larger hull is required for the larger displacement. Groups 4 and 5

TABLE II-1

WT GRP	WEIGHT / CHANGE	#1 BASE-LINE	#2 BASE-LINE + 20 TONS	#3 BASE-LINE +400 FT^2	#4 BASE-LINE +200 KW	#5 BASE-LINE +5 MEN	#6 BASE-LINE +ALL PARAM-ETERS
1	WEIGHT	1288.1	1292.9	1295.1	1293.9	1299.3	1317.0
HULL	CHANGE	-	4.8	7.0	5.8	11.2	28.9
2	WEIGHT	270.6	270.7	270.9	270.8	271.0	271.7
M.P.	CHANGE	-	0.1	0.3	0.2	0.4	1.1
3	WEIGHT	170.8	170.8	178.8	170.8	171.0	179.1
ELEC.	CHANGE	-	0.0	0.0	8.0	0.2	8.3
4	WEIGHT	108.2	108.3	108.2	108.3	108.3	108.4
ELEX.	CHANGE	-	0.1	0.0	0.1	0.1	0.2
5	WEIGHT	256.6	257.6	256.9	257.8	258.8	261.2
AUX.	CHANGE	-	1.0	0.3	1.2	2.2	4.6
6	WEIGHT	56.6	56.6	56.6	56.6	58.1	58.1
O.&F.	CHANGE	-	0.0	0.0	0.0	1.5	1.5
7	WEIGHT	392.0	412.0	392.0	392.0	392.0	412.0
ARM.	CHANGE	-	20.0	0.0	0.0	0.0	20.0
LOADS	WEIGHT	818.7	820.0	819.1	825.7	822.6	831.2
	CHANGE	-	1.3	0.4	7.0	3.9	12.5
FULL LOAD DISP	WEIGHT	3361.6	3388.9	3369.6	3383.9	3381.1	3438.7
	CHANGE	-	27.3	8.0	22.3	19.5	77.1

increase because they are dependent on the size of the ship. These weight growths in turn create smaller secondary effects similar to the ones just described and these secondary effects create even smaller tertiary effects, etc., until in the final iteration all of the effects have been accounted for.

Ship #3, the baseline with an additional space requirement of 400 square feet, shows similar effects. The major impact of the new space requirement is in Group 1 because of the structure required to house the space. The Group 1 growth causes a demand for additional SHP, Group 2, which in turn requires more fuel, loads. Because of the increase in the ship size and required SHP, Group 5, auxiliaries increases. Higher order effects of all of these increases continue in the same manner as in Ship #2 until all effects are accounted for.

The additional 200 KW electric load requirement for Ship #4 creates similar iterative effects. The increase in electrical load causes the size of the electric plant, Group 3, to grow with attendant increases in fuel requirement loads. The increased size of the electrical plant and fuel requirements cause the hull, Group 1, to grow. All of these increases require additional SHP, Group 2, and fuel, loads, electronics, Group 4, and auxiliaries, Group 5. The iterative effects of all of these changes are the same as previously described.

The major effects of the new manning requirement for Ship #5 are seen in the increased size of the hull, Group 1, to house the men, the auxiliaries, Group 5, which provide environmental services to the increased hull size, and the loads, which include the weight of the men and their personal effects. Outfit and furnishings, Group 6, increases because it is a function of the number of accommodations. All of these changes create requirements for additional SHP, Group 2, and electrical plant, Group 3, with attendant increases in fuel and other liquids, loads. Again, the iterative effects of all of these changes are as previously described.

The figures for Ship #6, the baseline ship with all of the additional requirements, show the combined effects of all of the above examples.

It is clear from the above discussion that the synthesis model takes into account not only the primary effects of parameter changes, but also the secondary, tertiary, and further effects of these changes.

Since marginal weight factors are developed directly from data generated by the synthesis model, they too account for all of the effects of parameter change. Assumption #2 is, therefore, valid.

Manual naval architectural calculations to determine the effects of the above parameter changes would follow

much the same iterative procedure as the synthesis model with the major difference being that engineering studies, rather than estimating relationships would be used to analyze the actual changes in each weight group.

Assumption 3. The marginal weight factors are valid and constant for the value (range) of equipment direct support parameters.

Since marginal weight factors are themselves only slopes of curves fitted to data points obtained by plotting the results of repeated parameter variations, one cannot say with confidence that the factors so obtained are valid outside the range of the points actually plotted. Within this range, however, their validity has been demonstrated in several cases (e.g. Reference 2) by favorable comparison of impact study results using MWF's with the results of computer impact studies. The only method presently known to develop marginal weight factors is a brute force one of generating many "different" ships about a baseline. When these "different" ships are generated, the range of parameter variation should be carried out far enough to cover any anticipated change to be evaluated with the MWF's. If this has not been done, the MWF's should not be used for parameter changes outside the range of development unless the user has some reason to believe that the MWF's are valid beyond this range. In some cases,

the user might feel confident in using the MWF's beyond their range of development because of previously conducted studies of linearity limits. For example, Howell (Reference 2) found that for his baseline frigate, the crew size could be varied from 48 to 318 men on a ship initially sized for a crew of 168 without encountering a linearity limit for the MWF for manning. He also found no linearity limit for the MWF for electrical power when the electrical load was varied between 1688 KW and 7838 KW. He did, however, encounter linearity limits of the MWF for weight and for removal of space requirements. No linearity limit was found for adding space requirements.

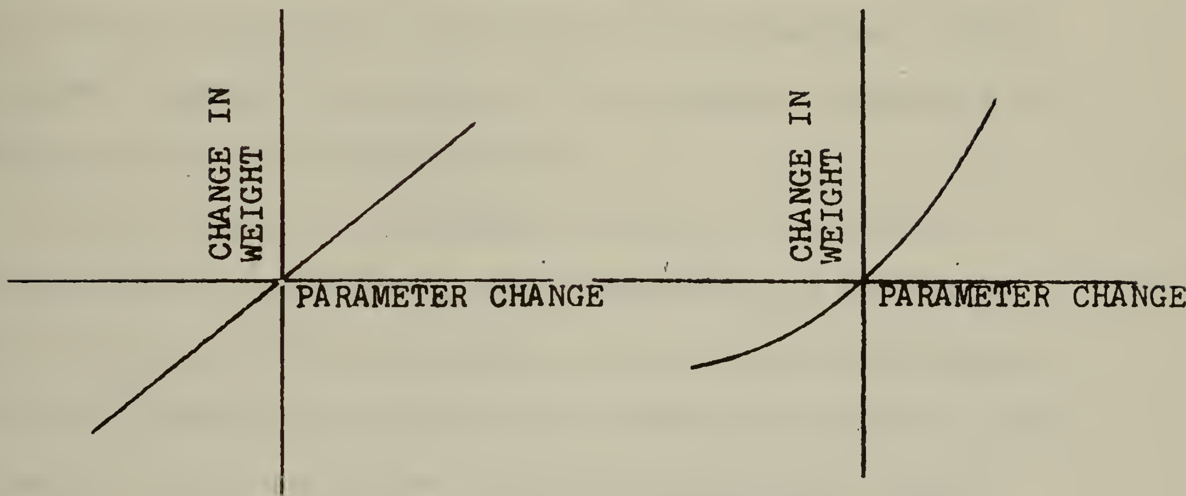
Related to the establishment of linearity limits is the second part of Assumption #3. That is, are the MWF's constant for the range of parameter variation? The factors are slopes of curves and, in the absence of linearity limit checks such as the ones mentioned above, there is no reason to assume that these curves are straight lines. That is, if when the data are plotted, the best fit curve is a straight line, then the marginal weight factor is constant. If the best fit curve is not linear, then the marginal weight factor is not constant and depends on the size of the parameter variation. It is conceivable that the marginal weight factor for a parameter is constant over a given range and then

varying outside the range such as Howell found with space variations. It is also conceivable that the marginal weight factor can be different, but constant, within different ranges of parameter variation. The latest case might occur when the MWF's are developed using discrete propulsion system or generating system size in the computer program input. For example, a baseline ship might have a functional electrical load of 900 KW (neglecting margins, etc.) but have a 1000 KW generator because the next smaller size generator on the input data list is only 750 KW. Then electrical load variations up to +100 KW will not cause the generator size to be changed, but a change slightly greater than 100 KW will cause a quantum jump in generator size to the next larger generator. Examples of MWF curves such as those discussed above are shown in Figure II-4.

The point to be made concerning Assumption #3 is that the developer of marginal weight factors must inform the user as to the range of MWF development, results of linearity checks, the shape of the curves in non-linear regions, and discontinuities in the curves. There is no reason that the marginal weight factor concept cannot be used in non-linear ranges of parameter variations. The developer would simply provide the user with the curves of change in weight versus change in parameter level and

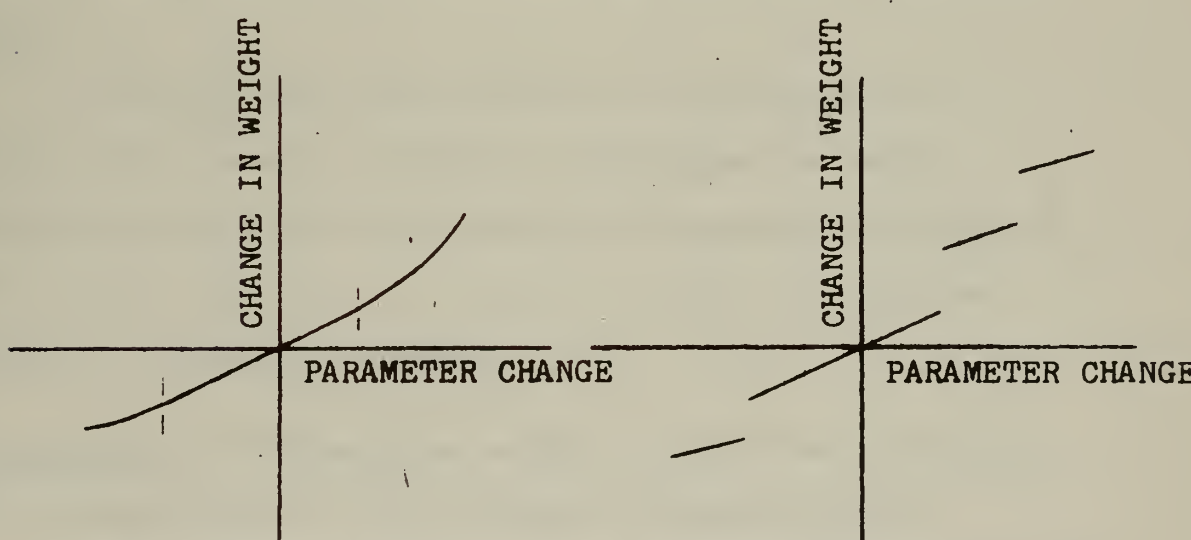
FIGURE II-4

EXAMPLES OF CONCEIVABLE MWF CURVES



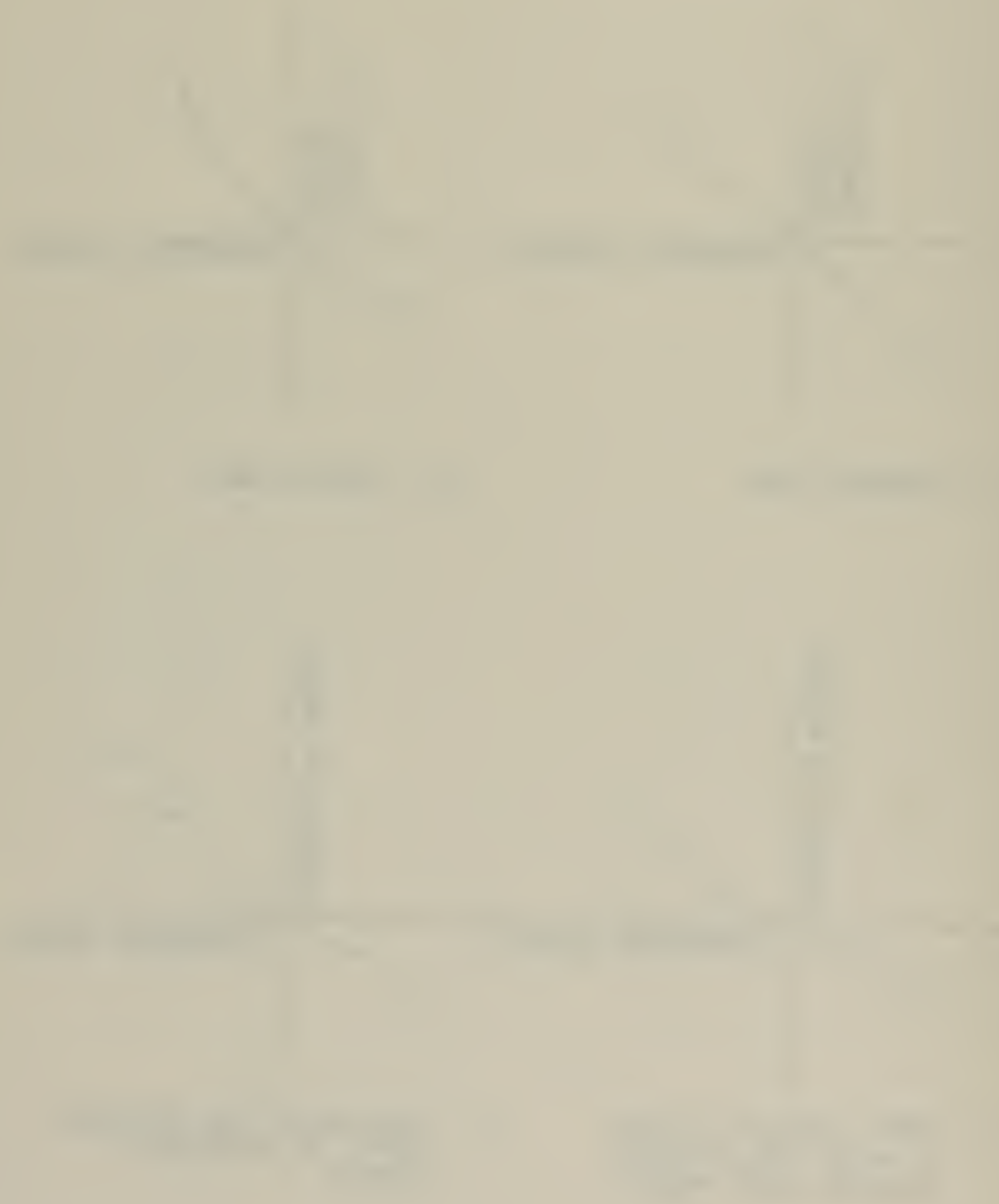
a. CONSTANT MWF

b. VARYING MWF



c. MWF CONSTANT WITHIN A RANGE AND VARYING OUTSIDE THAT RANGE

d. DIFFERENT BUT CONSTANT MWF'S IN DIFFERENT RANGES



let the user pick off weight changes corresponding to the parameter change he is investigating. This is an even more direct method than multiplying the parameter change by an MWF because the impact of the parameter change would be read directly from the curves.

To the author's knowledge, tests of the effect of simultaneously varying all four parameters at or near their limits of MWF development have not been conducted. The user of MWF's should be wary of MWF predictions if all parameters approach these limits simultaneously until such time as the effects of such variations have been tested. It is recommended that such tests be performed at the time of development of new MWF's for any baseline ship.

In manual naval architectural calculations, of course, the problem of ranges of equipment parameter variations would not arise because the manual calculations would be performed for the specific levels of equipment parameter changes in question.

<u>Assumption 4.</u> The marginal weight factors are valid for the equipment type or ship feature being evaluated.

Marginal weight factors are generally developed by varying the input parameter requirements of the payload items (the specific MWF's studied for this thesis were developed by varying the armament, Group 7, input

parameters). MWF's developed using this approach will not be valid for other types of equipment if the model's design process handles the support parameters for these different equipments/features in a manner that is not consistent with the manner in which it handles payload parameters. The four parameters will be addressed individually to point out where the design process does change depending on the equipment type or feature.

In the weight balance, Step 6, the weights of all weight groups are estimated and summed. Once this is done, the design process is indifferent to the breakdown of the specific weight groups as long as it is given, or can estimate, the VCG of the weight group for the stability balance. Since the marginal weight factor for weight (MWF_W) is dependent on the VCG of the weight change, and different values of MWF_W will be used for different VCG's, there is no differentiation in equipment types or ship features. MWF_W's developed using payload weight inputs are, therefore, valid for any equipment/feature.

In the space balance, Step 5, payload space is all considered to be arrangement space. As mentioned in the discussion of the space balance in Subsection B of this chapter, DD07 augments input electronics space by a factor of 1.23 and armament space by a factor of 1.15 as an allowance for payload storerooms, maintenance space and other support requirements not exclusively devoted to

an individual system but shared by several systems. Only the 1.15 factor is taken into account in armament-input-generated MWF_S's. Therefore, in using these MWF_S's with electronics equipments, the space requirement of the equipment should first be multiplied by a factor of 1.07 so that when this augmented space requirement is "multiplied" by the 1.15 that is "built into" the MWF_S's, the resultant will be 1.23 times the equipment's input space requirement (1.07 x 1.15 = 1.23). This procedure will be further discussed in Chapter IV. The 1.15 factor for armament space is commensurate with space allocations for storerooms, etc. for equipments/features other than electronics, so the armament-input-generated MWF_S's can be used without alteration for all other equipments/features that require arrangement space. If, however, the equipment or feature requires tankage or large object space, payload-developed MWF_S's are not strictly applicable because the model's procedure for sizing the ship to accommodate these requirements differs from its procedure for arrangement space requirements. For tankage space requirements, the MWF_S's developed from payload inputs can be used to find what might be termed a "maximum" impact. That is, since arrangement space can be converted to tankage space, the user of MWF's can assume that no excess tankage space is available and that the new tankage

requirement will occupy arrangement space. Since arrangement space cannot occupy irregularly-shaped parts of the ship, its impact on ship size is greater than that of tankage space and the user, by making the above assumption, can find the maximum possible impact of the additional tankage volume. A method of converting tankage volume to arrangement space is given in Chapter III. The major difference in large object space and arrangement space is that the size of the machinery box (large object space) determines the height of the shear line, the depth of the ship, in the model's design process. If a space requirement changes the height or breadth of this large object space, the rest of the design procedure is affected because the available tankage and arrangement space determinations in the space balance routine depend on the size of the machinery box as described in Section B of this chapter. If the large object space requirement under consideration can be assumed not to affect the height or breadth of the machinery box, but only its length, then the MWF_S's may be considered to be applicable because a change in machinery box length is equivalent to adding more arrangement space forward or aft of the existing machinery box with approximately the same height and breadth.

The model's design process treats all functional electric loads the same in determining the size and

capacity of the ship service and emergency generators. However, in calculating the average 24 hour electric load, which is used to determine the electric plant contribution to the endurance fuel load, the electric load for armament payload equipments is not considered. This means that armament-input-generated marginal weight factors for electricity will underestimate the impact of the electrical load requirements for equipments other than armament. The user of MWF's must use his own engineering judgement in deciding whether or not this underestimation will be of sufficient magnitude to invalidate the results of an MWF-based impact study. If the electrical load requirement of the equipment being studied is small, relative to the other parameters, the results will be accurate enough for a feasibility level study in spite of the endurance fuel load for electric power being ignored. If the electric load requirement is large, the user may use the MWF's in the normal manner, conduct a separate calculation of the endurance fuel requirement, and then use the marginal weight factors for weight and space required for this additional fuel to get the total ship impact of the equipment. A special procedure for overcoming this deficiency for electronics equipments is given in Chapter IV.

Manning requirements are not associated with any particular equipments as far as the model is concerned, so the marginal weight factors for manning are valid for any equipment or ship feature.

Marginal weight factors specifically applicable to any type of equipment or ship feature can be developed by varying the four support parameters of that equipment type or ship feature, but experience indicates that this is unnecessary, except for electronics equipments, for feasibility level studies. Chapter IV addresses a method of adapting MWF's based on armament inputs to use with electronics equipments.

In summary of the discussion of Assumption 4 thus far, and except for the two types of equipments to be mentioned below, the following can be said regarding armament-input-generated MWF's:

a. MWF_W's can be used with all equipments/features

b. MWF_S's can be used unaltered with all equipment/features requiring arrangement space except electronics (see Chapter IV for electronics equipments). MWF_S's can be used to find the maximum impact of tankage space requirements and can be used with equipments/features requiring large object space that will not alter the height or width of the machinery box

c. MWF_E's generally can be used unaltered with all equipments/features except electronics (see Chapter IV for electronics).

d. MWF_M's can be used with all equipment/features.

There are two additional types of equipment for which the use of MWF's is not recommended without concurrent calculations of impacts not accounted for by MWF's. The first is equipments which will alter the size or shape of appendages (including sonar domes). The propulsive SHP required to overcome appendage drag is calculated separately within the design process and is not changed (except through its dependence on ship size) by varying payload support parameters and is therefore not accounted for in MWF's developed by varying payload input parameters. The user of MWF's can overcome this deficiency by calculating the impacts of the equipment's weight, space, electrical, and manning requirements in the normal MWF fashion and then make separate calculations of the change in appendage drag. The appendage drag change can be handled as a decrease in the ship's sustained speed (considering the propulsive SHP to be unchanged) plus an increase in the endurance fuel load. The additional endurance fuel load would be handled in the same manner as previously described on Page 60.

The second type of equipment requiring additional concurrent calculations is equipments which draw their power from the prime mover. The MWF's do not account for this increased requirement on the size of the main

propulsion plant. The user of MWF's can handle the impacts of this type of equipment in the same manner described above for appendage changes.

Assumption 5. The four parameters W, S, E and M adequately describe the equipment's impact on the ship.

The direct weight, space, electrical, and manning requirements of equipments/features create the major impacts on the four major design tasks of the synthesis model's design process and are, therefore, accounted for specifically within the model. Many equipments require additional support in the form of heating, air conditioning, dry air, cooling water, compressed air or other gasses, steam, etc.. These other support requirements, of course, create impacts, but these impacts are secondary compared to the W, S, E, and M impacts and thus are calculated by empirical relationships to other ship or subsystem characteristics. It would be possible to "size" all support subsystems based on subsystem demand, but this would introduce complexity into the design process beyond justification for the amount of additional accuracy it would produce. Since the synthesis model does account for support requirements other than W, S, E, and M (although not specifically), the MWF's also include an allowance for these requirements and Assumption 5 is valid.

It should be mentioned here that the estimating relationships used in calculating support subsystems other than electrical are based on empirical studies of past equipments and designs. If the user of MWF's feels that the equipment he is evaluating has "abnormal" support requirements when compared to other equipments of the same type, he should make allowances for these requirements. This can be done by converting the "abnormal" requirements to electrical KW requirements and adding these to the equipment's direct electrical requirement. Methods for making some of these conversions are given in Subsection E of Chapter III.

Detailed manual naval architectural calculations of equipment/feature impacts would be much the same as the synthesis model/MWF procedure, but support parameter requirements other than W, S, E, and M would be the subject of specific analyses rather than empirical estimating relationships. These calculations, therefore, would be more accurate but would be unnecessary for the type of impact studies for which the synthesis model and marginal weight factors are used.

D. Summary

It can be concluded from this chapter that the use of marginal weight factors is a mechanically simple process and that the assumptions made in the concept are generally valid. Marginal weight factors generated by varying armament payload support parameters can be used unaltered with most equipments other than electronics and can be adapted to use with electronics equipments. In some special cases, additional calculations must be made to augment the use of marginal weight factors.

III DETAILED PROCEDURES FOR THE USE OF MARGINAL WEIGHT FACTORS

This chapter specifies the procedures to be followed in determining values of the marginal weight factor for weight and the equipment direct weight, space, electrical, and manning requirements. Items that should and should not be included in these values are given as well as methods of handling what the user of marginal weight factors considers to be "abnormally" high equipment support requirements.

The procedures in this chapter are applicable to all equipment types and ship features. Once the values of the equipment support parameters have been determined, they are used unaltered for all equipments and features other than electronics. The parameters for electronics must be altered by a method which will be given in Chapter IV before applying the marginal weight factors to find total ship impact.

Fill-in formats for tabulating equipment parameters and finding ship impacts are given in Appendix A and examples of using the procedures and fill-in formats are given in Appendix B.

The procedures in this chapter can also be used to standardize the method of determining armament and electronics payload item characteristics used as inputs

to computerized ship synthesis models. Until now there seems to have been no list of rules published for making these determinations.

A. Engineering Judgement Foreword

Before going into the detailed procedures for determining and using the four basic parameters for each equipment being evaluated, it should be stressed that these procedures cannot possibly cover all situations that might arise. The use of marginal weight factors is itself an approximating process that makes predictions based on the experience of past designs and uses thumb rules and generalities frequently. These thumb rules and generalities have been arrived at by studying numbers of past equipment designs, by taking recommendations from engineers at NAVSEC, by studying the process by which the ship synthesis model makes estimations and sometimes by engineering judgement of the author.

When the engineer evaluating an equipment makes use of these thumb rules and generalities, he should do so only because he has no better information available to him and he believes them to be applicable to his evaluation. If he has available to him more precise or accurate information, he should, by all means, make use of it. In many cases the equipment being evaluated will be one which is in actual use in an existing ship or has been

the subject of an in-depth engineering study elsewhere. In those cases the engineer should glean all the information he can from the previous installation or study to determine actual values for the weight, space, electrical, and manning requirements of the equipment. The engineer must also make many judgement decisions based on his own experience or knowledge of the baseline ship design with which he is working. An example of a judgement decision of this sort is the question of whether or not to include in an equipment's overall space requirement the space on a deck which is penetrated only one or two feet by the equipment. In this case the engineer must make use of his knowledge of usual deck height for the ship type, the equipment location on the ship, and what other equipments or spaces might be affected before making his decision. A further discussion of this particular question is included in the section on determination of equipment space, S.

In short, it is emphasized that the thumb rules and procedures here should in no way be allowed to usurp the sound judgement of a competent engineer or to replace more reliable information from any source.

B. Determining Marginal Weight Factors for Weight, MWF_W

Marginal weight factors for equipment/feature weight

depend on the vertical location of the weight itself with respect to the ship's baseline. In Reference 2, Howell discussed the manner in which MWF_W's varied with vertical location for several ships. For some ships in that study it was found that the MWF_W increased with vertical location and for others it decreased as vertical location increased. One would normally expect the MWF_W to increase with increasing vertical location because of the adverse effects on ship stability associated with high weights and the necessity for the synthesis model's design process to overcome these adverse effects by increasing ship draft or hull size. It was only because certain peculiar geometries and limiting conditions were encountered in Howell's work that some MWF_W's decreased with vertical location in some cases. It was found, however, that the MWF_W's for all ships varied linearly with vertical location. Therefore, once the MWF_W's for given vertical locations are known for a baseline ship, the MWF_W's for intermediate locations are found by linear interpolation between the values of the known locations. The reference point for vertical locations, or, more specifically, vertical centers of gravity (VCG), is the ship's main deck at station ten (mid-length). This reference point is used because it is the reference point used within the synthesis model for payload inputs.

The MWF_W will normally be developed for three locations; at the main deck, a number of feet below the main deck, and a number of feet above the main deck. How far above and below the main deck will depend on the ship size and type, but the distances should be large enough to include the locations of all equipments for which the marginal weight factors might be used. In cases where the height of an equipment is above or below the height for which MWF_W's have been developed, the engineer may use linear extrapolation to find the applicable MWF_W.

An example of the MWF_W interpolation process follows:

Known MWF_W's: 1.36 tons/ton 20 feet below the main deck

1.57 tons/ton at the main deck

1.94 tons/ton 40 feet above the main deck

Equipment VCG: 32 feet above the main deck

$$MWF_W = 1.57 + \frac{32}{40}(1.94 - 1.57) = 1.87 \text{ tons/ton.}$$

C. Determining Equipment Weight, W

The value assigned to W should represent the best estimate of the direct weight impact, in tons, of all components of the equipment/feature being evaluated. If a design feature, rather than an equipment, is being evaluated, the engineer will have to conduct a study to determine the change in the baseline ship weight due to that particular feature and use that weight as W.

Component weights should include not only the weight of the components themselves but also the weight of water and working fluids in the components and sumps - that is, wet weights of the components should be used. Replenishment working fluids are not included in W. Ammunition weight must be included in W as should the weight of non-propulsion or non-electrical plant fuel. For instance, helicopter fuel would be included in W. A VCG of 13.5 feet below the main deck is normally used for helicopter fuel but if the engineer feels that this is not representative of the intended location of the fuel, he should use a different value for fuel VCG. Propulsion and electrical plant fuel weights are calculated within the synthesis process and are therefore accounted for in MWF_W.

The weights of ship service support subsystems such as heating, air conditioning, cooling water, compressed gasses, etc. are calculated within the model and are, therefore, accounted for in MWF_W. However, if an equipment requires a support system that is dedicated solely to that equipment and is not shared by other equipments, the weight of this support system must be included in W. The same rationale applies to tools and workshop equipment. For example, an electronics test set that is used only in association with a particular

radar system should be included as a component weight of that radar system, but a meter that would normally be included in the radar technicians' tools for general use would not be included.

Spare parts weights are also calculated within the model's design process. However, if an equipment has a requirement for on-site spares, that is, spares that are not kept in supply storerooms but rather in the vicinity of the equipment itself, the weight of these spares should be included as a component weight of the equipment. An example of this might be spare fins for a missile system which are kept on-site in the missile magazine. These fins would be included in W, while a circuit board for the missile which becomes part of the ship's supply department spares would not.

The weights of intakes and exhausts for aspirated equipments must also be included in W unless they will become part of an existing system. For example, the weights of the intake and exhaust for an additional emergency diesel generator would be included if the generator is expected to be in a location which will not allow its system to be tied in with the intakes and exhausts of other machinery. The same rationale applies to cooling water inlets and outlets.

The synthesis model estimates the weights of

electric power distribution cabling and switchboards as well as lighting systems so these items should not be included as component weights, but cabling and switching systems that are part of an equipment, such as intercabinet cabling in a fire control system, should be included in W.

The synthesis model also estimates the weight of equipment foundations so foundation weight is not normally included as a component weight. However, in some instances equipments are installed as units with the foundations included and in others special foundation requirements exist because of shock and blast or other criteria. In these cases the rule to follow is that if the foundation weight is less than ten percent of the equipment weight, the foundation weight is not counted. If the foundation weight is greater than ten percent of the equipment weight, then the excess over ten percent must be counted as a component weight of the equipment. Where special requirements such as this exist, it is up to the engineer evaluating an equipment to determine how much weight effect the special requirements will cause.

Some equipments might require what the engineer considers to be "abnormal" structural support. This might happen when an engineer is evaluating a small, but very heavy, equipment which will create large localized loads on a deck. In this case the engineer will have to assess

the weight impact of the additional structure required to strengthen the deck and include it as a component weight. The word "abnormal" has been put in quotes because there is no precise definition of what is normal and what is not in ship systems. The user of MWF's must keep in mind that the estimating relationships used in the synthesis model have been derived from empirical studies of other ship designs. If, using his own engineering judgement, he concludes that any of the requirements of the equipment being evaluated are "abnormal" with respect to past designs, he must take the "abnormality" into account when using MWF's.

In summary of this subsection so far, the key questions the engineer must ask in determining whether or not a weight should be included in W are:

1. Would the component not be on the ship if the equipment system were not there?
2. Is the component dedicated solely to this equipment?
3. Is the component located with or near the equipment (e.g. spare parts, etc.)?
4. Are there any requirements that, in his best judgement, the engineer considers to be "abnormal"?

It should be pointed out here that only the vertical location of a weight is specified in using synthesis models/ MWF's. Longitudinal and horizontal positions are not specified.

In tabulating component weights, the weights may be tabulated individually, in groups, or as a whole for the equipment system. The point to be kept in mind is that the marginal weight factor for equipment weight, MWF_W, varies with the equipment's vertical location, VCG. It is, therefore, convenient to group the components which will be physically near each other in order to facilitate the estimation of VCG's used to determine the value of MWF_W to be used with that particular component or group of components.

D. Determining Equipment Space, S

The value assigned to S should represent the best estimate of the actual compartment space requirement, in square feet, of all components of the equipment/feature which are located on enclosed decks within either the hull or the deckhouse. Weather deck space is not included in space requirements because the synthesis model sizes the ship internally and assumes enough weather deck space will be available for topside arrangements. In all feasibility studies conducted using the DD07 model, the topside arrangement should be checked manually. If a design feature, rather than an equipment, is being evaluated, the engineer will have to conduct a study to determine the <u>change</u> in the baseline internal space due to that particular feature and use that space as S.

When evaluating an equipment, the spaces to be included in S are the arrangement compartment space requirements for the equipment components, magazines, any special access area such as clear internal deck area for torpedo loading, and internal working space for the equipment itself.

The synthesis model design procedure makes a space allocation for ship service support systems such as heating, air conditioning, pump and compressor rooms, etc. and this allocation is, therefore, included in MWF_S. However, if an equipment requires some support system that is dedicated solely to that equipment and is not shared by other equipments, the space required for this support system must be included in S. For example, an electronics equipment that requires its own environmental control system in the equipment compartment, or a special compartment, must have that compartment space included in its overall space requirement. A similar equipment that uses the ship's installed environmental control system would not receive a special space allocation for this support requirement. This same rationale applies to workshop spaces. If the equipment requires a dedicated workshop, the compartment space of this workshop is included in S regardless of the location of the workshop.

As was the case in deciding whether or not to make a weight allocation for spare parts and tools, the decision

of whether or not to make a space allocation for these items is basically a question of location. If the spare parts and tools for an equipment must be kept in special spaces or in the vicinity of the equipment item rather than being kept in supply storerooms or ship's workshops, then space must be allocated for them. The model makes space allowances for supply storerooms and ship's workshops not exclusively devoted to a single equipment and this allowance is included in the value of MWF_S.

Space must be allocated for intakes and exhausts that are not tied into an existing ship's system.

Space must also be allocated for the fuel requirements of non-propulsion and non-electrical plant equipments. Without having access to a description of the baseline ship, the user of MWF's does not know if excess tankage space already exists. As outlined in the discussion of Assumption 4 in Section II C, he should assume that no excess tankage space exists and find the "maximum" space impact of the fuel requirement by allocating arrangement-type space to it. With the assumption that the fuel for the equipment will occupy arrangement-type space, the space requirement is found by multiplying the fuel volume by an expansion factor of 1.05 and a structure factor of 1.02, and then dividing by the deck height. In the absence of a known deck height, the engineer may use nine

feet as an average deck height. The density of JP-5 fuel is approximately 44 cubic feet per ton. Using this density and a deck height of nine feet, the conversion factor from tons of JP-5 to square feet of space becomes:

Space required (ft^2) = 5.24 x JP-5 weight (tons).

As previously mentioned in Chapter II, the space balance routine in the model's design process makes allocations for compartment access and passageways. The allocation for electronics spaces is larger than that for other spaces, but this difference is adjusted in the method of adapting existing MWF's to use with electronics equipment outlined in Chapter IV. Compartment access space is, therefore, not included in S. Equipment access, on the other hand, is not estimated within the model and should be included in S. Equipment access is access space needed within a compartment for either operation or maintenance of an equipment.

In the specifications for many equipment systems the manufacturer gives information as to what compartment sizes are required for the equipments. If the engineer has this information available, or if he has knowledge of the same or similar equipment systems having been installed on, or studied for, other ships he should use these known compartment sizes as the value for S.

In cases where the engineer has no information

available to him as to compartment size either recommended by the manufacturer or used in previous installations or studies, there are two methods which he may use to arrive at an estimate of S. The first, and probably best, of these two methods is to make a rough arrangement drawing himself, utilizing whatever knowledge he has regarding equipment size, operator space requirements, equipment repair and maintenance space requirements, and any special requirements of the equipment. In making this arrangement drawing, the question of vertical arrangement will often arise. That is, should less compartment deck space be allocated for system components which can be stacked on top of each other or mounted over-and-under each other on a bulkhead or in equipment shelf arrangements? The answer to this question is yes, less space should be allocated for these types of components than would be allocated if each component had to sit on the deck itself. In considering vertical arrangements of this sort, though, the engineer must take into account the necessity of allowing enough space for operation and maintenance of each component in a vertical arrangement, any restrictions as to component proximity to other components, and requirements for special mountings such as shock mounts. An average deck height of nine feet may be assumed for making these vertical arrangements with the understanding that only approximately seven-and-a-half of this nine feet

is actually available for component arrangements. The remaining height should be assumed to have been used by structures, cableways, lighting, insulation, vent ducts, etc.

A special case of this vertical arrangement question is equipments that have vertical dimensions larger than a deck height. An example might be a gun mount ready service magazine which penetrates down through the deck below the deck cn which the gun is mounted. The question is, should a space allocation be made on the deck into which an equipment penetrates either from above or below? The answer to this question will depend on the engineering judgement of the engineer making the equipment evaluation. If the engineer thinks the equipment will penetrate, say, six feet into a deck from either above or below, it is apparent that he must include space on that deck in his value of S because the area below or above a penetration this deep would be essentially useless for any other purpose. On the other hand, the area below or above a smaller penetration of, say, one foot might very well still be usable for other purposes. The engineer must make a judgement, using all available knowledge, as to whether or not a small penetration into a deck renders that deck area useless for other purposes and, if so, must include the deck area in the space allocation for the

equipment making the penetration. In the absence of better information, and remembering that space allocations are only made for internal deck space, a useful thumb rule is that any penetration greater than two feet into a deck should receive a space allocation on that deck, or, any internal equipment with a vertical dimension greater than eleven feet requires space on two decks, and greater than twenty feet, three decks. This thumb rule is based on the experience of engineers at the Naval Ship Engineering Center.

The second method of estimating required compartment size, S, when no other information is available is to total the actual areas (length x width) of each component of the equipment and multiply this total by a "space utilization factor" of 2.5. This author derived this factor by taking a number of "typical" payload-type systems for which recommended or known space requirements were available and dividing these requirements by the total of the actual measured areas (length x width) of all the components of the equipment system. These quotients were then averaged to arrive at the space utilization factor of 2.5. The equipment types and spaces used in this study are shown in Table III - 1. Again, the systems in this study were typical payload-type systems so the reader is cautioned not to be overly confident in applying this

TABLE III-1

EQUIPMENT TYPE	(1) REQUIRED SPACE (FT^2)	(2) TOTAL OF COMPONENT AREAS (FT^2)	(3) (1)/(2)
1. Large Gun Mount (Surface)	408	347.0	1.2
2. Medium Gun Mount Control Panels	45	17.7	2.5
3. Medium Gun Mount	130	59.2	2.2
4. Guided Missile Launching System (Not Including Magazine)	72	35.4	2.0
5. Gun Fire Control System	75	45.7	1.6
6. Long Range Air Search Radar	180	83.0	2.2
7. Short Range Surface/Air Search Radar	96	12.0	8.0
8. Long Range Air Search Radar	196	78.5	2.5
9. Short Range Surface/Air Search Radar	27	18.3	1.5
10. Target Acquisition System	130	75.0	1.7
		AVERAGE:	2.5

space utilization factor to non-payload systems. In this case a rough arrangement drawing would be a better method of finding the compartment space requirement.

In summary, the general rule to follow in deciding whether or not space should be allocated in S for an equipment component is that if the component requires internal space that would not be on the baseline ship were it not for the component's presence, and that space is not usable for other purposes, then a space allocation must be made.

E. Determining Equipment Electrical Requirements, E

Assigning a value to E, the equipment/feature electrical power requirement, is not always a straightforward, clearcut task. The engineer must use all information available to him in order to arrive at a value of E which best represents the actual increase in the generator plant capacity resulting from the addition of the equipment being investigated. In general, E should be the functional load, in kilowatts (KW), of the equipment where functional load is defined as the electrical power required by the equipment while the ship is performing its designed function. For example, the designed function of a destroyer is battle; for an aircraft carrier, air operations; for a cargo ship, debarking operations; and for a combat support or stores ship, replenishment of ships at sea.

The functional load of an equipment is arrived at by multiplying the connected load (rated KW input) by an operational load factor for the functional condition. Careful consideration should be given to the selection of operational load factors because of their influence on the value of E. Each equipment application must be considered from such standpoints as its service operation in the power system and its functional operation as determined by the type of ship involved and the type of service the ship performs. The Naval Ship Engineering Center has compiled a list of typical operational load factors for surface ships and submarines in a Design Data Sheet (DDS 9610-2, dated 1 May 1970) which is an excellent reference on this subject. No single method for determining operational load factors is specified, but conditions which have a general bearing on their selection and typical methods which may be used in their selection are listed below.

1. <u>Relation of the horsepower rating of the driving motor to actual horsepower consumed by the driven auxiliary</u>

In selecting the size of a motor necessary to drive an auxiliary at its rated output, a larger motor than actually required by the auxiliary is normally chosen because:

a. In the design of the driven auxiliary,

some margin in excess of calculated horsepower is allowed. The motor design also provides some margin. Accordingly, the driving motor is not normally required to deliver its rated horsepower when operating the driven auxiliary at its maximum load condition.

b. The choice of available standard motor frame size may dictate selection of a larger than necessary motor. In view of this fact, it may be assumed that an auxiliary operating at its full output is not requiring the rated output of its driving motor.

2. <u>Assignment of a load factor to each individual load</u>

If a particular equipment operates continuously at a steady load during a given ship operational condition, the factor for that equipment may be taken as the ratio of the actual operating load to the connected load of the equipment expressed as a decimal. If a load is intermittent, such as an air compressor motor, the factor should be selected so as to reflect:

a. The ratio of the actual load to the connected load of the equipment and;

b. The effect of intermittent duty of the equipment on the generator load. Known or anticipated ship operating procedures and practices, and characteristics of operation of the equipment involved, should be considered in estimating this effect.

3. <u>Assignment of a factor to a group of loads</u>

A single load factor may be assigned to a group of loads under the following conditions:

a. When two or more associated power consuming devices are known to operate with some relation to each other. This method may be used where the relationship of the loads to one another is clearly established. For example, in considering the group of motors associated with the operation of a particular gun mount, a clearly established relationship might exist between the ramming motors and elevating motors, since the rammers operate under load only when the barrels are horizontal, and the elevating motors are idling under no load.

b. When the relationship of the loads is not so clearly established but is known to exist. An example of this is a group of electrical loads in a galley where the electrical equipment in operation during the preparation of a fried meal may be different from that equipment which would be in operation during the preparation of a broiled or baked meal.

c. When there is a group of low power consuming equipment within the same space and which would be assigned approximately the same load factor. An example of this is a group of electronic equipments.

For some equipment and groups of equipment, extensive investigations and tests have been conducted

to determine operating load values during various ship operating conditions for use in preparing electric power analyses. If such known and established operating load values are available to the engineer they should, of course, be used.

An operational load factor of zero is normally assigned to equipment that is seldom used and a factor of 0.9 is used in cases where a motor operates at full load for an extended period of time during a specific ship condition.

Maximum average operating loads should be used as the connected load for electric ordnance drives, rather than instantaneous peak values. The latter represent a transient condition of very short duration during the initial application of the supply voltage to the stalled motor of the weapons drive. Generators and distribution systems are normally capable of handling such transient power surges well beyond their nominal rating without any detrimental effects on the performance of the equipment. This procedure brings the philosophy for selection of the connected ordnance load in line with the practice for selection of the connected load for all other auxiliaries on the ship.

If an equipment requires other than 60 Hertz electric power, that power requirement should be added to the

connected 60 Hertz power with a suitable allowance for conversion loss before applying the load factor to find the functional load, E.

As has been previously mentioned in Subsections C and D of this chapter, the characteristics of ship service equipment support systems are estimated within the synthesis model. Equipment requirements for these services are, therefore, accounted for in the marginal weight factors. The additional electrical plant capacity for these support systems is included in MWF_E and need not be included in the value of E unless, in the engineer's judgement, the equipment has an "abnormally" high requirement for some support service such as heating, air conditioning and ventilation, cooling water, or compressed gasses. If this is the case, the engineer should assume that the support requirement will be provided by a support system solely dedicated to the equipment he is evaluating and include the electrical requirements of this dedicated support system in the value of E. Some equipments, of course, will already include their own dedicated support system located in its own space and which is not part of the normal ship's system, and the electrical requirements of these systems must be included in E. The reader is reminded that the weight, space, and manning requirements of these dedicated support systems must be included in the

values assigned to W, S, and M respectively.

An important support service that is not presently taken into account specifically by synthesis models, but which might be a major impact feature in future designs, is an equipment's automatic data processing (ADP) requirements. As ship equipment systems become more automated, their demands on a central computer system will be comparable to their demands on a central electric supply system. In this case a marginal weight factor for computer services will have to be developed. At present, though, ADP requirements are not specifically considered.

Some thumb rules used by engineers at NAVSEC for converting non-electrical support requirements to electrical KW requirements are listed below.

For circulating (blowing) air, one horsepower is required for every one thousand cubic feet of air per minute. One horsepower is equivalent to approximately 0.75 KW. To air condition air, every three hundred to three hundred fifty cubic feet of air per minute requires one ton of refrigeration and each ton of refrigeration requires 1.25 horsepower or 0.94 KW. The average efficiency of the equipments involved is included in the conversion factors. A system that requires blown air conditioned air must have the blowing requirement and the refrigeration requirement added. For example, if a hypothetical system

required 5000 cubic feet of blown air conditioned air per minute the conversion would be as follows:

REFRIGERATION:

$$5000 \text{ CFM} \times \frac{1 \text{ ton}}{350 \text{ CFM}} \times \frac{1.25 \text{ HP}}{\text{ton}} \times \frac{1 \text{ KW}}{1.34 \text{ HP}} = 13.3 \text{ KW}$$

BLOWING:

$$5000 \text{ CFM} \times \frac{1 \text{ HP}}{1000 \text{ CFM}} \times \frac{1 \text{ KW}}{1.34 \text{ HP}} = 3.7 \text{ KW}$$

The total KW requirement would then be 17.0 KW.

For some systems the manufacturer specifies how much heat is dissipated into the compartment in terms of KW. A direct conversion from heat dissipation KW to electrical power required from the generators which takes into account the above NAVSEC figures is, for every KW of heat dissipated into the compartment 0.27 KW of electrical power will be required.

In the case of a cooling water system there are two requirements as in the air conditioning system; one for cooling the water, and one for pumping the water. For cooling the water, the electrical requirement in KW is equal to .001 times the number of gallons per minute times the expected temperature drop of the water. For example, a requirement of an equipment might be 100 gallons per minute at 50°F. If the ship is expected to operate with an average sea water injection temperature of 60°F then the conversion would be as follows:

$$100 \text{ gal/min} \times (60^{\circ}\text{F} - 50^{\circ}\text{F}) \times .001 = 1 \text{ KW}$$

For pumping water, the water horsepower is equal to the number of gallons per minute times the head, in feet, times the density of the water, in pounds per cubic feet, divided by a conversion factor of 247,000. This water horsepower is then converted to brake horsepower by dividing by the pump efficiency and finally the conversion to required electrical load is made by dividing the brake horsepower by 1.34 HP/KW. A normal value for pump efficiency is 0.70, the density of fresh water is 62.4 pounds per cubic foot and the density of sea water is 64.0 pounds per dubic foot. For an example of figuring electrical power requirements for pumping water assume that a system must have 300 gallons per minute of sea water pumped with a head of twenty feet. The conversion is as follows:

$$\text{Water HP} = \frac{300 \text{ gal/min} \times 20 \text{ ft} \times 64 \text{ lb/ft}^3}{247{,}000} = 1.6 \text{ HP}$$

$$\text{Brake HP} = \frac{1.6 \text{ Water HP}}{.70} = 2.2 \text{ BHP}$$

$$\text{KW} = \frac{2.2 \text{ BHP}}{1.34 \text{ BHP/KW}} = 1.7 \text{ KW}$$

A centralized hydraulic system is not normally installed on a ship, but for equipments that have dedicated hydraulic systems, the conversion from hydraulic horsepower to electrical KW is made by dividing the hydraulic horsepower by the efficiency of the hydraulic pump and then multiplying by 0.75 KW/HP. For example, a system requiring 27 hydraulic horsepower and with a hydraulic

pump efficiency of 0.65 will require 31.2 KW of electrical power found as follows:

$$\frac{27\ HP}{0.65} \times .75\ \frac{KW}{HP} = 31.2\ KW$$

In summary of this section, the value to be assigned to E is the functional load, in KW, of the equipment being evaluated. Functional load is found by multiplying the connected load by an appropriate load factor. The electrical load of equipment support requirements is not included in E unless the equipment has a dedicated support system or has what the engineer considers to be an abnormally high support requirement, in which case he will consider this requirement to be satisfied by a dedicated support system. In the case of a dedicated support system, the weight, space, and manning requirements of the system, as well as the electrical requirements, must be accounted for.

F. Determining Equipment Manning Requirements, M

M should represent the engineer's best estimate of the additional number of men that will be required on the baseline ship because of installation of the equipment/feature being evaluated. This number can be dictated by the operational manning requirements of the equipment or its maintenance requirements, but must be the larger of the two requirements. Manufacturer's

specifications normally give the operational requirements of the equipment but not the maintenance requirements, so this figure must be obtained from another source. The best source for this information on specific equipments is the Manpower Determination Model (MDM) developed by the Shipboard Manning/Design Work Study/Human Factors Section of the Naval Ship Engineering Center. The output of the MDM gives the manning requirements for equipments in ship Readiness Conditions I, III, and V. Condition I is general quarters, with all hands at battle stations. Condition III is wartime cruising, with one third of the crew on watch and only certain stations manned or partially manned, and Condition V is peacetime in port, enough personnel on board to get the ship underway if necessary or to handle fires and similar emergencies. The MDM manning requirements are broken down into required skills and pay grades. In using the information from the MDM, the engineer cannot simply take the equipment totals for each Condition of Readiness without further consideration of the skills and paygrades involved because many equipments require a certain number of personnel for maintenance and then for operation of the equipment during Condition I some personnel may be cross-utilized from other divisions or departments on the ship. The maintenance personnel and some of the operational

personnel might require no specific skills. For example, a given gun mount might require two skilled men during Condition III and eight men during Condition I, three of whom are skilled gunner's mates and five of whom are ammunition handlers requiring no skilled rating. The engineer's problem is to decide how many of the required personnel in each Condition of Readiness must actually be added to the ship because of the equipment addition and how many will be cross-utilized from existing ship's personnel. This, of course, will depend on the skill levels required for the equipment and the manning level of the baseline ship. It can be assumed that all skilled personnel required for the equipment will be new additions to the ship's crew because of the equipment addition, but the same assumption cannot be made for non-skilled personnel. These non-skilled personnel might be cross-utilized from the existing crew. On a small ship with a "tight" manning level, little cross-utilization will be possible while on a larger ship or one with a "loose" manning level a high degree of cross-utilization might be possible. The engineer must use his own judgement based on his knowledge of the baseline ship manning policy to decide how many non-skilled personnel can be cross-utilized.

The value of M should be the number of personnel required in the Condition of Readiness that requires the

maximum number of personnel where the required number in each Condition of Readiness is the number of skilled personnel plus the number of non-skilled personnel who will not be cross-utilized from other functions. In the absence of better information, the engineer may resort to a thumb rule used at NAVSEC which says that fifteen percent of an equipment's maximum personnel requirements will be cross-utilized from other sources. No differentiation between officer and enlisted personnel is made when using MWF's.

The MDM lists manning requirements in tenths of men. For use with marginal weight factors the total manning requirement for each Condition of Readiness may be rounded off to the nearest integer.

If an equipment is not listed in the MDM, the engineer may use the manning requirements for a similar equipment type which is listed in the MDM or make his own estimate of the required manning and use the fifteen percent cross-utilization thumb rule, again rounding off to the nearest integer.

Ortmann, in Reference 5, found that for every five watchstanders and maintenance personnel on a U. S. Navy ship an average of one additional crew member is required for personnel support functions such as administration, supply, messing, etc. If an equipment has a personnel

requirement of five men, an additional man should be allocated for this support function. If the equipment requires ten personnel, two additional men should be allocated, etc. Intermediate values of equipment personnel requirements do not receive support personnel allocations. For instance, an equipment requirement for three men would receive no support personnel allocation; a requirement for eight men, one support personnel.

G. Determining Total Ship Weight Impact, I_{TOT}

Once W, S, E and M have been determined for the equipment components and their respective MWF's are known, the total ship weight impact of the equipment is found by multiplying each support parameter by its marginal weight factor and summing these products. As previously mentioned, for these tabulations and calculations, work sheets containing brief instructions can be found in Appendix A of this thesis. Separate work sheets are provided for non-electronic equipments and electronic equipments because of the differences in handling the space and electrical requirements of electronics equipment which will be discussed in Chapter IV. Examples of determining support parameter values and applying marginal weight factors are given in Appendix B.

H. Summary

From the procedures outlined in this chapter it can be concluded that the marginal weight factor concept is a relatively easy method of determining equipment/feature impacts on a ship for feasibility level studies. The reader is reminded that the level of detail in a feasibility study is much lower than in the later stages of design. He should not, therefore, expend unwarranted effort in determining extremely precise values of equipment/feature support parameters but, rather, should concentrate on consistency among studies of different equipments/features.

The reader is further reminded that the literature shows that values of marginal weight factors vary with ship size, geometry, and design standards. The MWF's used for impact studies, therefore, should be ones developed for the specific baseline ship in question.

IV METHOD OF ADAPTING EXISTING MARGINAL WEIGHT FACTORS TO USE WITH ELECTRONIC EQUIPMENTS

As discussed in Chapter I, Howell, in Reference 2, reported poor correlation between armament-input-generated marginal weight factor predictions of the ship weight impact of electronics equipments and DD07 synthesis model predictions of the ship weight impact of the same equipments. He recommended development of marginal weight factors that would be specifically applicable for electronics equipments by varying electronics payload input parameters. Development of these factors would, of course, require access to the DD07 model, which the author did not have at the time of this work. In lieu of development of these factors, an attempt has been made to discover why the existing armament-input-generated MWF's do not work for electronics equipments and to devise a way of adapting them to these equipments in a manner that will provide at least a temporary method for getting MWF predictions of electronic equipment impacts that agree reasonably well with DD07 predictions. This temporary method can be used until MWF's for electronics equipments can be developed.

The first step in attempting to adapt existing MWF's to electronics equipments was to compile a list of ten different electronics equipments ranging from very small to very large in terms of size and support

requirements. Five of these equipments were the five that Howell reported on and the remaining five were chosen because their size and support requirements were in the intermediate range between the extremes of Howell's original five. The impacts of these ten equipments on full load displacement of Howell's baseline frigate were then predicted using DD07 and marginal weight factors and the results tabulated. The predictions of the original five equipments were taken from Reference 2 and the DD07 predictions for the five additional equipments were performed by Mr. Howell at NAVSEC. For each equipment a ratio was then taken of the DD07 prediction to the MWF prediction. The equipment characteristics, the predictions, and the ratios are tabulated in Table IV-1. (The right-hand column in this table will be explained later.) Next, a plot of the ratios of the DD07 predictions to the MWF predictions versus the MWF predictions was made in hopes of exposing a generalized factor by which the MWF predictions could be multiplied to bring them more in line with the DD07 predictions. This plot is shown in Figure IV-1. As can be seen from this figure, no such factor was exposed at the smaller impact end of the plot but a factor of about 1.27 seems to be reasonable at the higher end. It was felt that the use of this factor for all sizes of electronics equipments would be feasible, if no better method of adapting

TABLE IV-1

MWF_W = 1.36 TONS/TON 20 FEET BELOW MAIN DECK

MWF_W = 1.57 TONS/TON AT MAIN DECK

MWF_W = 1.94 TONS/TON 40 FEET ABOVE MAIN DECK

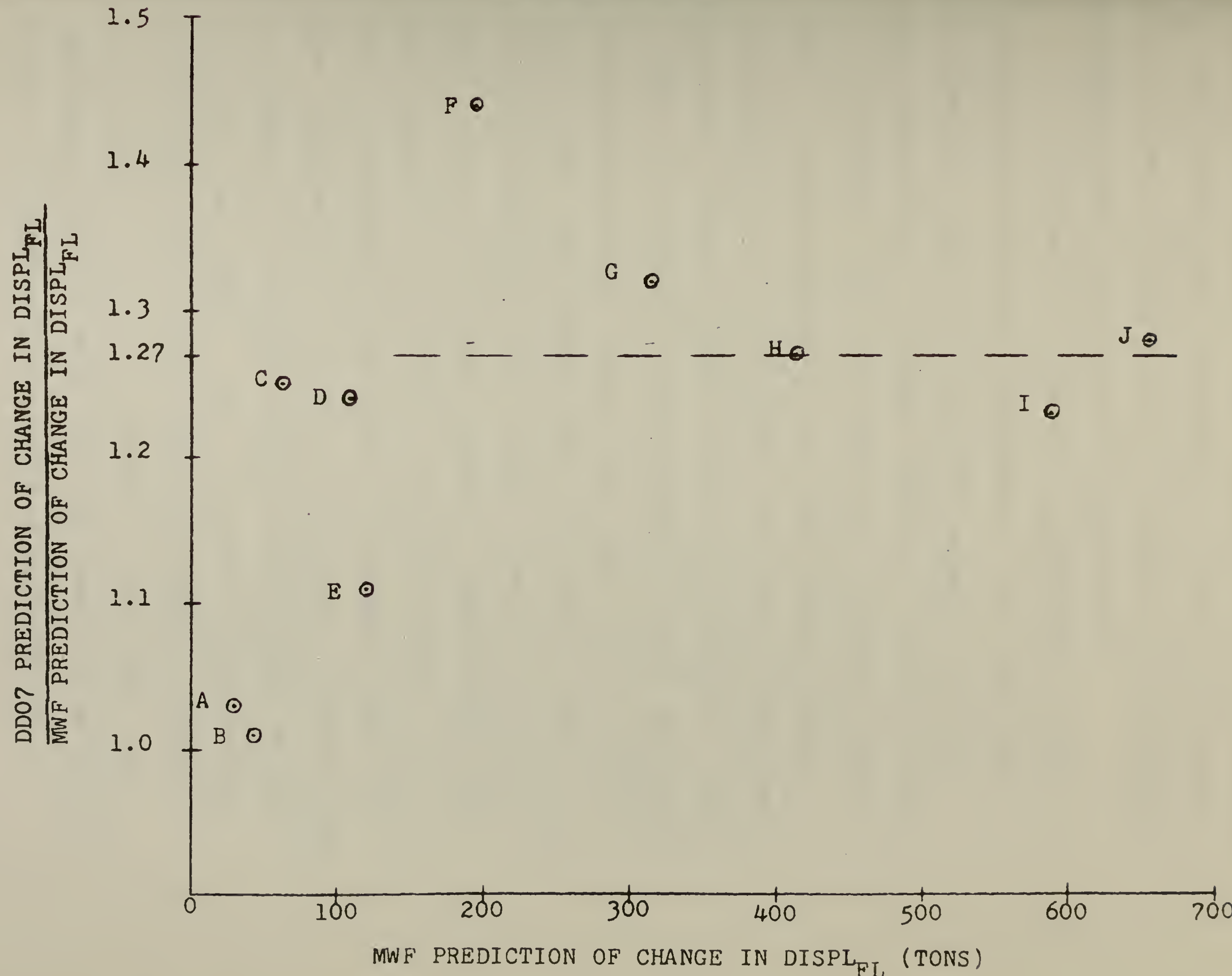
MWF_S = 0.0608 TONS/FT^2

MWF_E = 0.096 TONS/KW

MWF_M = 5.7 TONS/MAN

EQUIPMENT SYSTEM	W TONS	VCG FEET ABOVE (+) BELOW (-) MAIN DECK	S SQUARE FEET	E KILOWATTS	M MEN	PREDICTED CHANGE IN FULL LOAD DISPLACEMENT BY:		DD07 / MWF	MOD. MWF / DD07
						DD07	MWF		
A	1.0	+24.0	100	10	4	32.7	31.6	1.03	1.03
B	2.2	+15.0	119	10	6	46.1	45.3	1.01	1.06
C	6.0	+24.5	350	85	4	78.9	63.0	1.25	1.02
D	21.2	- 4.0	500	145	6	136.9	110.7	1.24	1.03
E	26.6	- 4.0	1025	12	3	134.0	121.2	1.11	0.95
F	53.0	+20.0	1000	265	3	284.0	196.4	1.44	0.88
G	81.5	+20.0	1600	405	6	413.0	313.3	1.32	0.96
H	109.0	+20.0	2200	545	6	524.0	412.1	1.27	1.00
I	137.4	+17.7	3802	700	9	721.0	587.9	1.23	1.02
J	156.1	+18.2	3902	866	11	838.9	654.7	1.28	1.00

FIGURE IV-1



DD07 PREDICTION OF CHANGE IN DISPL$_{FL}$ / MWF PREDICTION OF CHANGE IN DISPL$_{FL}$
1.5
1.4
1.3
1.27
1.2
1.1
1.0
A
B
C
D
E
F
G
H
I
J
0
100
200
300
400
500
600
700
MWF PREDICTION OF CHANGE IN DISPL$_{FL}$ (TONS)

existing MWF's could be found, because the errors produced by its use with smaller equipments would not be of great magnitude and it would be fairly accurate for high-impact equipments where errors would be more serious.

In the attempt to find out why the MWF's do not work well with electronics equipment it was found (as mentioned in Chapter II) that DD07 augments the input space requirements of armament items by a factor of 1.15 and electronics items by a factor of 1.23 before using them in the space balance step of the design process. This augmentation is an allowance for payload storerooms, maintenance space, and other support requirements. Since the MWF's were developed using armament inputs, they take into account the 1.15 factor rather than the 1.23 factor that the DD07 space balance takes into account when electronics equipments are properly input as electronics items. This is one reason that MWF's underestimate the DD07 predictions of electronic equipment impacts. In order to overcome this problem, it is proposed that the space requirements of electronics equipments be multiplied by a factor of 1.07 before applying the marginal weight factor for space, MWF_S. The 1.07 factor was arrived at by dividing 1.23 by 1.15. Using this factor, the MWF_S will now "see" a space requirement of 1.07 times the electronics input and when this requirement is multiplied by the 1.15 factor which is built into the MWF_S the

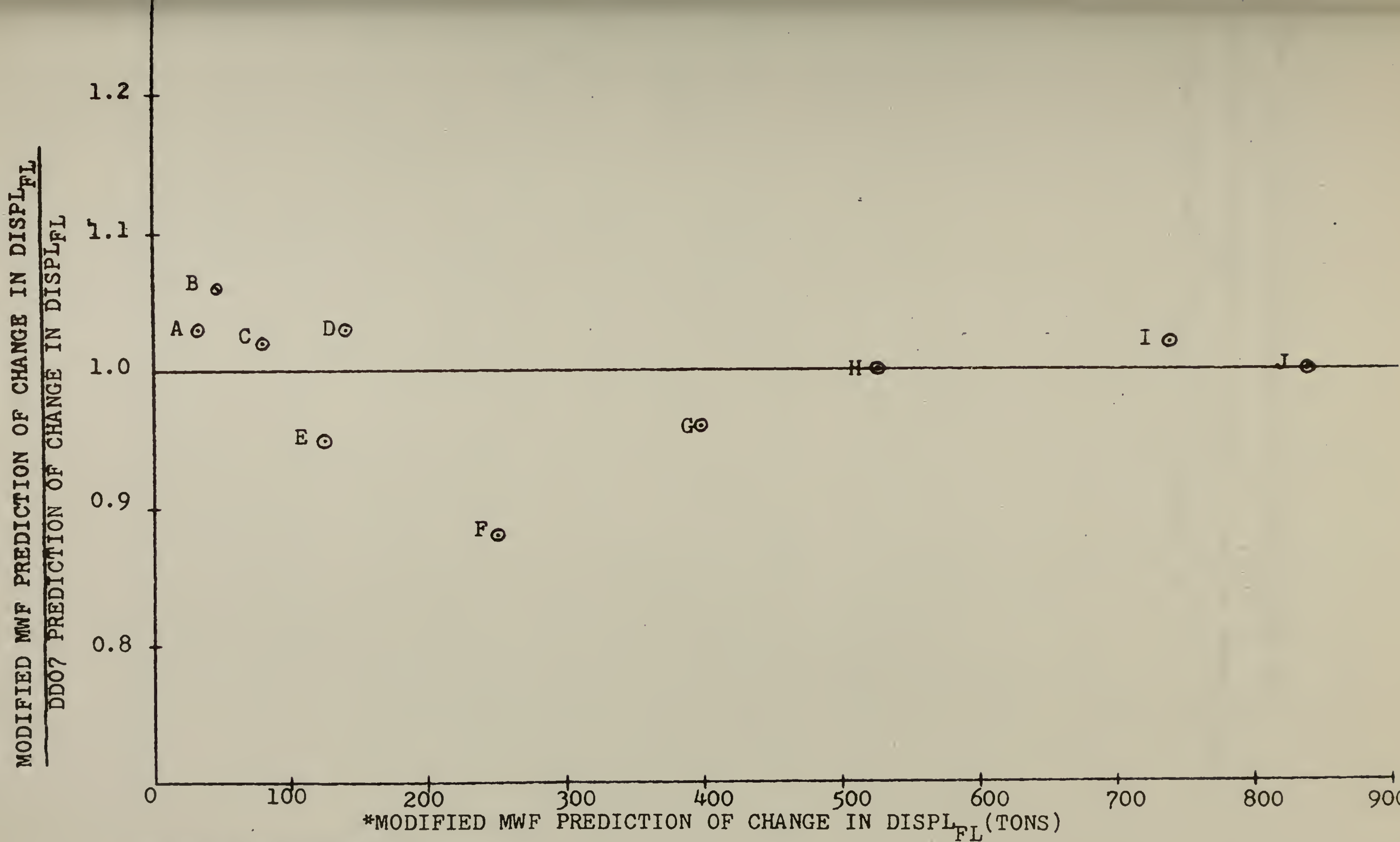
resultant requirement will be 1.23 times the input requirement, just as is done in the DD07 space balance.

A second reason that the marginal weight factors underpredict the impact of electronics equipments has to do with the amount of required endurance fuel calculated by the model. As explained in Chapter II, the electrical requirements of armament payload equipments are not considered in calculating the average 24 hour electric load, which is used to determine the electric plant contribution to the endurance fuel load. Armament-input-generated MWF_E's, therefore, do not take into account the contributions that electronics equipments should make to the endurance fuel load and the attendant weight and space impacts of this fuel. To counterbalance this effect, it was proposed to multiply the electrical power requirements of electronics equipments by a factor greater than 1.0 before applying MWF_E to "trick" the marginal weight factors into increasing the ship weight impact of the equipment's electrical requirements.

For the ten electronics equipments studied, "modified" MWF predictions of impact on full load displacement of the baseline frigate were calculated by multiplying their space requirements by 1.07 and their electrical requirements by several different factors before applying MWF_S and MWF_E to find out which combination made these

modified predictions compare most favorably with the DDO7 predictions. It was found that a combination of multiplying the space requirements by the 1.07 factor and the electrical requirements by a factor of 3.0 made the modified MWF predictions compare favorably with the DDO7 predictions. The ratios of these modified MWF predictions to the DDO7 predictions are tabulated in the right hand column of Table IV-1 and are plotted versus the modified MWF predictions in Figure IV-2. For all ten equipments the ratios fell reasonably close to 1.0. The worst modified prediction (Equipment F) underestimated the full load displacement impact by twelve percent of the DDO7 prediction with all others falling within six percent of the DDO7 predictions. Very good results were obtained for the three largest systems with one prediction being off by two percent and the other two being exactly the same as the DDO7 prediction.

On the basis of these results it is proposed that, until MWF's for electronic equipments are developed, existing armament-input-generated MWF's be adapted to use with electronics equipments by multiplying the equipment's space requirement, S, by 1.07 and its electrical requirement, E, by 3.0 before multiplying them by MWF_S and MWF_E respectively. The procedures for determing S and E should still be as outlined in Chapter III. The



*SPACE REQUIREMENT X 1.07
KW REQUIREMENT X 3.0

above proposal is reflected in the Work Sheets for Electronics Equipments in Appendix A and is demonstrated in the electronics examples of Appendix B.

V CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Conclusions drawn from Chapters II through IV of this thesis can be summarized as follows:

1. The baseline ship weight impact of one equipment support parameter or ship feature requirement can be found by multiplying the value of that parameter or requirement by the corresponding marginal weight factor, and the total impact of an equipment or ship feature change can be found by summing the individual parameter impacts.

2. The four parameters necessary for finding the impact of an equipment or feature are its weight, space, electrical, and manning requirements.

3. Marginal weight factors account for both the direct and indirect effects of equipment and ship feature changes.

4. Marginal weight factors are not necessarily constant over a full range of possible parameter changes, but the marginal weight concept can still be used even if the MWF's are variable.

5. Armament-payload-generated marginal weight factors are not applicable to all types of equipments or ship features, but the concept can still be used in conjunction with additional calculations. It is possible

to develop marginal weight factors for any specific type of equipment or ship feature change.

6. Existing armament-payload-generated marginal weight factors can be adapted to use with electronics equipments.

7. In view of the above conclusions and the procedures outlined in Chapter III, the marginal weight factor concept is a relatively accurate and simple procedure that can be applied by persons without an in-depth knowledge of ship design. Weight-based marginal cost factors can be developed, from marginal weight factors, which will enable the user to determine the dollar cost of sizing a baseline ship to accommodate an equipment or ship feature.

B. Recommendations

The marginal weight factor has been shown to be valid, accurate, and easy to use and can be a valuable, time and money-saving tool to any organization involved in shipbuilding. It is therefore recommended that the concept be further implemented by the U. S. Navy. To improve the concept, additional work is recommended in the following areas:

1. Marginal weight factors specifically applicable to electronics payload equipments should be

developed since much use of the concept will be in evaluating these payload items.

2. A method of determining what support parameter requirements are considered "abnormal" should be developed to eliminate inconsistencies that might occur between the engineering judgement of different designers.

3. A method of predicting marginal weight factors from baseline ship characteristics should be developed to eliminate the "brute force" method of generating MWF's for each specific baseline ship.

4. The entire set of marginal weight factors should be converted to marginal cost factors, cost being defined as acquisition and life cycle dollar costs.

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APPENDIX A : WORKSHEETS

This appendix contains work sheets which may be used in the calculations required to find the ship weight impact of adding an equipment to a baseline ship. The instructions on the worksheets are procedural only and the user of the worksheets should familiarize himself with the contents of Chapter III of this thesis before using them.

Separate worksheets are provided for electronics equipments to reflect the special procedures for this type of equipment developed in Chapter IV.

WORK SHEETS FOR NON-ELECTRONIC ITEMS

EQUIPMENT: ______________________

BASELINE SHIP: ______________________

MWF_W = ________tons/ton ___feet below main deck at mid-length

________tons/ton at main deck at mid-length

________tons/ton ___feet above main deck at mid-length

MWF_S = ________tons/ft^2 MWF_E = _____tons/KW MWF_M = ____tons/man

NON-ELECTRONIC WEIGHT IMPACTS:

(a) COMPONENT	(b) W (tons)	(c) VCG (ft)	(d) MWF_W (tons/ton)	(e) I_W (tons)
			(f)	ΣI_W =

(a) Component name.

(b) W is the weight, in tons, of the component.

(c) VCG is the vertical center of gravity, in feet, above (+) or below (-) the main deck at mid-length.

(d) MWF_W is the marginal weight factor for weight, in tons per ton, for the component. MWF_W depends on the VCG of the component and is found by linear interpolation between the known MWF_W's.

(e) I_W is the ship weight impact, in tons, of the component weight. $I_W = W \times MWF_W$.

(f) ΣI_W is the sum of the component I_W's.

NON-ELECTRONIC SPACE REQUIREMENT IMPACTS:

COMPONENT	(g) S (ft^2)	(h) MWF_S ($tons/ft^2$)	(i) I_S (tons)

(j) ΣI_S =

(g) S is the space requirement, in square feet, of the component.

(h) MWF_S is the marginal weight factor for space, in tons per square foot.

(i) I_S is the ship weight impact, in tons, of the component space. $I_S = S \times MWF_S$

(j) ΣI_S is the sum of the component I_S's.

NON-ELECTRONIC ELECTRICAL REQUIREMENT IMPACTS:

COMPONENT	(k) E (KW)	(l) MWF_E (tons/KW)	(m) I_E (tons)
		(n)	ΣI_E =

(k) E is the functional electrical load requirement, in kilowatts, of the component.

(l) MWF_E is the marginal weight factor for electrical requirements, in tons per kilowatt.

(m) I_E is the ship weight impact, in tons, of the component electrical requirements. $I_E = E \times MWF_E$.

(n) ΣI_E is the sum of the component I_E's

NON-ELECTRONIC MANNING REQUIREMENTS IMPACTS:

COMPONENT	(o) M (men)	(p) MWF_M (tons/man)	(q) I_M (tons)

(r) $\Sigma I_M =$

(o) M is the manning requirement, in number of men, of the component.

(p) MWF_M is the marginal weight factor for manning, in tons per man.

(q) I_M is the ship weight impact, in tons, of the component manning requirements. $I_M = M \times MWF_M$.

(r) ΣI_M is the sum of the component I_M's.

TOTAL NON-ELECTRONIC IMPACT:

ΣI_W	
ΣI_S	
ΣI_E	
ΣI_M	
(s) I_{TOT} =	

(s) I_{TOT} is the total ship weight impact, in tons, of the equipment and is found by summing ΣI_W through ΣI_M.

WORK SHEETS FOR ELECTRONIC ITEMS

EQUIPMENT:________________________

BASELINE SHIP:____________________

MWF_W =_________tons/ton______feet below main deck at mid-length

_________tons/ton at main deck at mid-length

_________tons/ton______feet above main deck at mid-length

MWF_S =_________tons/ft^2 MWF_E=_____tons/KW MWF_M=____tons/man

ELECTRONIC WEIGHT IMPACTS:

(a) COMPONENT	(b) W (tons)	(c) VCG (ft)	(d) MWF_W (tons/ton)	(e) I_W (tons)
			(f)	ΣI_W =

(a) Component name.

(b) W is the weight, in tons, of the component.

(c) VCG is the vertical center of gravity, in feet, above (+) or below (-) the main deck at mid-length.

(d) MWF_W is the marginal weight factor for weight, in tons per ton, for the component. MWF_W depends on the VCG of the component and is found by linear interpolation between the known MWF_W's.

(e) I_W is the ship weight impact, in tons, of the component weight. $I_W = W \times MWF_W$

(f) ΣI_W is the sum of the component I_W's

ELECTRONIC SPACE REQUIREMENT IMPACTS:

COMPONENT	(g) S (ft^2)	(h) S_M (ft^2)	(i) MWF_S ($tons/ft^2$)	(j) I_S(tons)
			(k)	ΣI_S =

(g) S is the space requirement, in square feet, of the component.

(h) S_M is the modified space requirement of the component. $S_M = 1.07 \times S$.

(i) MWF_S is the marginal weight factor for space, in tons per square foot.

(j) I_S is the ship weight impact, in tons, of the component space. $I_S = S_M \times MWF_S$

(k) ΣI_S is the sum of the component I_S's.

ELECTRONIC ELECTRICAL REQUIREMENT IMPACTS:

COMPONENT	(l) E (KW)	(m) E_M (KW)	(n) MWF_E(tons/KW)	(o) I_E(tons)
			(p)	ΣI_E =

(l) E is the functional electrical load requirement, in kilowatts, of the component.

(m) E_M is the modified electrical requirement of the component. $E_M = 3 \times E$.

(n) MWF_E is the marginal weight factor for electrical requirements, in tons per kilowatt.

(o) I_E is the ship weight impact, in tons, of the component electrical requirements. $I_E = E_M \times MWF_E$

(p) ΣI_E is the sum of the component I_E's.

ELECTRONIC MANNING REQUIREMENT IMPACTS:

COMPONENT	(q) M (men)	(r) MWF_M (tons/man)	(s) I_M (tons)
		(t)	ΣI_M =

(q) M is the manning requirement, in number of men, of the component.

(r) MWF_M is the marginal weight factor for manning, in tons per man.

(s) I_M is the ship weight impact, in tons, of the component manning requirements. $I_M = M \times MWF_M$.

(t) ΣI_M is the sum of the component I_M's.

ELECTRONIC TOTAL IMPACT:

	ΣI_W	
	ΣI_S	
	ΣI_E	
	ΣI_M	
(u)	I_{TOT} =	

(u) I_{TOT} is the total ship weight impact, in tons, of the equipment and is found by summing ΣI_W through ΣI_M.

APPENDIX B : EXAMPLES

This appendix gives four examples of the use of marginal weight factors and the use of the worksheets in Appendix A. Examples A and B are examples of non-electronic equipments for which no specialized procedure is needed. Examples C and D are examples of electronics equipments for which the special procedures of Chapter IV are needed. The numerical tabulations and calculations are recorded on the worksheets found at the end of each example. In the first non-electronics example, Example A, and the first electronics example, Example C, the specific worksheet columns used are referred to in the discussion, but this specific reference is omitted from Examples B and D to avoid tedium.

In all four examples the baseline ship is considered to be Howell's baseline frigate with the following marginal weight factors:

MWF_W = 1.36 tons/ton 20 feet below the main deck at mid-length

= 1.57 tons/ton at the main deck at mid-length

= 1.94 tons/ton 40 feet above the main deck at mid-length

MWF_S = 0.0608 tons/ft^2 MWF_E = 0.096 tons/KW

MWF_M = 5.7 tons/man

EXAMPLE A: GUN MOUNT

In this example the ship weight impact of adding a gun mount to the baseline ship is found. The mount includes the gun house on the open deck and a ready-service 20-round ammunition drum that extends nine feet into an enclosed compartment directly under the gun house. A control panel, a power panel, and a hydraulic accumulator are also located in the below-decks area adjacent to the ammo drum and are included as components of the gun mount. Replenishment of ammunition in the ready-service drum is manual from a conveniently located ammo stowage magazine.

The overall wet weight of the mount is 47,820 pounds, which includes the control and power panels at approximately 2200 pounds each and the accumulator at 1170 pounds. The below-decks compartment, excluding the off-mount ammo stowage magazine, must be 10 feet by 13 feet by 9 feet high. The ammunition stowage magazine will carry 600 rounds of ammunition at 115 pounds each and will require a compartment containing 200 square feet of area.

The mount requires 440V, 60 Hz, 3 phase electrical power and has an average firing load of 101 KW.

During operation the personnel requirements are one mount captain, one panel operator, and four ammo handlers for the off-mount replenishment magazine.

All other support requirements of this mount (e.g.

heating and cooling) are considered to be normal. That is, this mount has no "abnormally large" support requirements.

Impact of Gun Mount Weights:

From the information above, and referring to available manufacturer's drawings, the weights and vertical centers of gravity with respect to the main deck are estimated for the different components of the gun mount system and recorded on the worksheet, Columns (b) and (c). The MWF_W's for each component weight are then calculated by linear interpolation between the known MWF_W's and recorded for each component in Column (d). The weights and MWF_W's for each component are then multiplied and the products recorded in Column (e). These component I_W's are then summed to find the ship weight impact, ΣI_W, of the gun mount system weight. $\Sigma I_W = 82.76$ tons.

Impact of Gun Mount Space:

Using the thumb rule that an internal equipment of ten feet or less in height need not have deck space allocated on more than one deck, it is determined that the space requirement of the gun mount is 130 square feet. The space requirement of the off-mount ammo stowage magazine is given as 200 square feet. These requirements are recorded in Column (g) of the worksheet and the MWF_S's recorded in Column (h). The space requirements

and MWF_S's are then multiplied to find the component space impacts, I_S, which are recorded in Column (i) and summed to find the ship weight impact, ΣI_S, of the gun mount system space requirements. $\Sigma I_S = 20.06$.

<u>Impact of Gun Mount Electrical Requirements</u>:

The average firing load of the gun mount is given as 101 kilowatts. A typical operating load factor for a gun mount might be .7. The average firing load is multiplied by the operating load factor to find the gun mount's functional load, which is the value to be used for E, and recorded in Column (k) of the worksheet. E = 70.7 KW. MWF_E is then recorded in Column (l) and multiplied by E to find I_E, the impact of the component's electrical requirement, which is recorded in Column (m). The component I_E's are then summed to find the ship weight impact, ΣI_E, of the gun mount system electrical requirements. In this example the electrical requirements of all components are lumped together so no summation is actually made. $I_E = 6.79$.

<u>Impact of Gun Mount Manning Requirements</u>:

The gun mount requires six men during operation. Reference to the Manpower Determination Model (MDM) shows that for a gun mount of this type the operational, Condition I, manning requirement is larger than the Condition III or Condition V requirement and is therefore

the controlling requirement. It might be assumed that the four Condition I ammunition handlers can be drawn from existing shipboard personnel, in which case the additional manning requirement of the gun mount would be two men. However, considering that in this example the gun mount is being added to a relatively small destroyer-type ship which probably has few men not already assigned during Condition I, it is more conservative to use the 15% cross-utilization thumb rule in determining the additional manning requirement, M. Hence, eighty-five percent of the six man operational requirement of the gun mount must be new personnel. Eighty-five percent of six is 5.1 men, which rounds down to 5 men. As described in Chapter III, for every five men added to a ship, one additional support personnel must be added for such purposes as administration, supply services, messing, etc. The value to be assigned to M, then, is the five non-cross-utilized mount operators plus the one support personnel, or M equals six men. This value of M is recorded in Column (o) of the worksheet and then multiplied by MWF_M, which is recorded in Column (p). The product of M and MWF_M is the impact, I_M, of the mount manning requirement, and is recorded in Column (q). The summation of the I_M's is, of course, the same as the mount I_M in this case because only one system is being recorded on the worksheet. $\Sigma I_M = 34.20$.

Note: In an actual situation, the user of MWF's for this gun mount would probably want to make three separate manning impact calculations and present the results of all three as part of his final analysis. The three calculations would be for two men (all ammo handlers cross-utilized), six men (15% cross-utilization), and seven men (no cross-utilization).

Total Impact of Gun Mount:

Finally, the total ship weight impact, I_{TOT}, of adding the gun mount to the baseline ship is found by adding $\sum I_W$, $\sum I_S$, $\sum I_E$, and $\sum I_M$. Therefore, when the gun mount in this example is added to the baseline ship, the ship's full load displacement will increase by 143.81 tons.

WORK SHEETS FOR NON-ELECTRONIC ITEMS

EQUIPMENT: EXAMPLE A: GUN MOUNT

BASELINE SHIP: FRIGATE

MWF_W = 1.36 tons/ton 20 feet below main deck at mid-length

1.57 tons/ton at main deck at mid-length

1.94 tons/ton 40 feet above main deck at mid-length

MWF_S = 0.0608 tons/ft^2 MWF_E = 0.096 tons/KW MWF_M = 5.7 tons/man

NON-ELECTRONIC WEIGHT IMPACTS:

(a) COMPONENT	(b) W (tons)	(c) VCG (ft)	(d) MWF_W (tons/ton)	(e) I_W (tons)
1. Gun house, barrell and ready-service magazine	18.86	+4	1.61	30.30
2. Accumulator	0.52	-5	1.52	0.79
3. Control panel	0.98	-5	1.52	1.49
4. Power panel	0.98	-5	1.52	1.49
5. Ammunition in ready-service magazine. 20 rounds @ 115 lbs.	1.02	-3	1.54	1.57
6. Ammunition in stowage magazine. 600 rounds @115 lbs	30.80	-4	1.53	47.12
			(f)	ΣI_W = 82.76

(a) Component name.

(b) W is the weight, in tons, of the component.

(c) VCG is the vertical center of gravity, in feet, above (+) or below (-) the main deck at mid-length.

(d) MWF_W is the marginal weight factor for weight, in tons per ton, for the component. MWF_W depends on the VCG of the component and is found by linear interpolation between the known MWF_W's.

(e) I_W is the ship weight impact, in tons, of the component weight. $I_W = W \times MWF_W$.

(f) ΣI_W is the sum of the component I_W's.

NON-ELECTRONIC SPACE REQUIREMENT IMPACTS:

COMPONENT	(g) S (ft^2)	(h) MWF_S ($tons/ft^2$)	(i) I_S (tons)
1. Below-decks compartment	130	0.0608	7.90
2. Ammo magazine	200	0.0608	12.16

(j) $\Sigma I_S = 20.06$

(g) S is the space requirement, in square feet, of the component.

(h) MWF_S is the marginal weight factor for space, in tons per square foot.

(i) I_S is the ship weight impact, in tons, of the component space. $I_S = S \times MWF_S$

(j) ΣI_S is the sum of the component I_S's.

NON-ELECTRONIC ELECTRICAL REQUIREMENT IMPACTS:

COMPONENT	(k) E (KW)	(l) MWF_E (tons/KW)	(m) I_E (tons)
1. Gun mount system	70.7	0.096	6.79
		(n)	$\Sigma I_E =$ 6.79

(k) E is the functional electrical load requirement, in kilowatts, of the component.

(l) MWF_E is the marginal weight factor for electrical requirements, in tons per kilowatt.

(m) I_E is the ship weight impact, in tons, of the component electrical requirements. $I_E = E \times MWF_E$.

(n) ΣI_E is the sum of the component I_E's

NON-ELECTRONIC MANNING REQUIREMENTS IMPACTS:

COMPONENT	(o) M (men)	(p) MWF_M (tons/man)	(q) I_M (tons)
1. Gun mount system	6	5.7	34.20
		(r)	$\Sigma I_M = 34.20$

(o) M is the manning requirement, in number of men, of the component.

(p) MWF_M is the marginal weight factor for manning, in tons per man.

(q) I_M is the ship weight impact, in tons, of the component manning requirements. $I_M = M \times MWF_M$.

(r) ΣI_M is the sum of the component I_M's.

TOTAL NON-ELECTRONIC IMPACT:

ΣI_W	82.76
ΣI_S	20.06
ΣI_E	6.79
ΣI_M	34.20
(s) I_{TOT} =	143.81

(s) I_{TOT} is the total ship weight impact, in tons, of the equipment and is found by summing ΣI_W through ΣI_M.

EXAMPLE B: EMERGENCY DIESEL GENERATOR SET

In this example the ship weight impact of adding an extra emergency diesel generator set is found. The generator set supplies 500 KW of emergency power and has a wet weight of 11,200 pounds including the manufacturer-supplied foundation, all piping and heat exchanger, and all intake and exhaust piping and mufflers. The exhaust stack must penetrate the deck above the generator before discharging overboard and will occupy four square feet of space on that deck, including insulating requirements. The starting battery bank and charger weigh 600 pounds and measure six square feet in area. The dimensions of the generator set itself are 136 inches long, 66 inches high, and 48 inches wide. The generator switchboard is an integral part of the generator set. A 300 gallon fuel service tank must be located in the same compartment as the generator set.

The battery charger requires a $60H_z$ electrical input of 1 KW.

The generator set is unmanned during operation, and reference to the MDM shows that the maintenance requirement for this generator set is 0.3 man.

Impact of Generator Set Weights:

The generator set weight of 11,200 pounds includes the foundation weight of 1,000 pounds. Marginal weight

factors take foundation weights into account assuming the ratio of foundation weight to equipment weight is no greater than about one tenth. If the foundation-weight-to-equipment-weight ratio is less than one tenth, the foundation weight should not be included when applying MWF_W's. If the foundation-weight-to-equipment-weight ratio is above one tenth, the foundation weight in excess of one tenth of the equipment weight should be added to the equipment weight before applying the MWF_W's. In the case of this example, the foundation-weight-to-equipment-weight ratio is less than one tenth so the foundation weight is not included in the value of component weight, W.

The weight of generator fuel is not included as a component weight because the marginal weight factors take into account propulsion and electrical plant fuel requirements. The emergency generator set in this example will only operate in situations in which the normal ship service generators are not working and will use fuel that has already been supplied for these ship service generators. In other words, the new generator set does not add a new fuel requirement but rather an alternate use of fuel that is already aboard.

From the above information and the engineer's proposal as to the location of the emergency diesel

generator set the weights, W, vertical centers of gravity, VCG, and MWF_W's are found for the different components. The applicable MWF_W's are found by linear interpolation between the known MWF_W's depending on the component VCG. These values are all recorded in the proper columns of the worksheet. The component weights are then multiplied by their respective MWF_W's to get the component impacts and these component impacts are summed to find the total ship weight impact, ΣI_W, of the generator set weights.

$\Sigma I_W = 7.27$.

Impact of Generator Set Space:

In this example it is assumed that the engineer has no manufacturer's recommendations of space requirements for the generator set compartment, but does know the equipment maintenance access requirements, so he has made a rough arrangement drawing of the proposed emergency generator room. Detailed arrangement drawings are not necessary for use with MWF_S's since the space figures required are gross total space requirements of the equipment compartments. The MWF_S's account for passageway space external to the compartment and compartment access space. They do not, however, account for equipment access within the compartment so this requirement must be included in the equipment space requirement, S. It is assumed here that the engineer's rough arrangement drawing

shows a total compartment size of 266 square feet, including the generator set, a large equipment access requirement, batteries and charger, and fuel service tank. This example points out that in cases where large equipment maintenance access areas are needed, or other special requirements exist, the Chapter III thumb rule of multiplying actual equipment area by 2.5 should not be used (in this case the ratio is 4.0 based on the projected deck areas of the generator set, batteries and charger, and fuel service tank).

The component space requirements, S, are recorded on the worksheet, multiplied by MWF_S, and summed to find the ship weight impact, $\sum I_S$, of the generator set space requirements. $\sum I_S = 16.42$.

Impact of Generator Set Electrical Requirements:

The only electrical requirement of the generator set is the 1 KW requirement of the battery charger. This requirement is insignificant, particularly when a small operational load factor which is normally assigned to this type of equipment is applied. The electrical requirement is, therefore, ignored. $\sum I_E = 0$.

Total Impact of the Generator Set:

The total ship weight impact, I_{TOT}, of the generator set is found by adding $\sum I_W$, $\sum I_S$, $\sum I_E$, and $\sum I_M$. Therefore,

when the emergency diesel generator set in this example is added to the baseline ship, the ship's full load displacement will increase by 23.69 tons (see worksheet).

WORK SHEETS FOR NON-ELECTRONIC ITEMS

EQUIPMENT: EXAMPLE B: EMERGENCY DIESEL GENERATOR SET

BASELINE SHIP: FRIGATE

MWF_W = 1.36 tons/ton 20 feet below main deck at mid-length

1.57 tons/ton at main deck at mid-length

1.94 tons/ton 40 feet above main deck at mid-length

MWF_S = 0.0608 tons/ft^2 MWF_E = 0.096 tons/KW MWF_M = 5.7 tons/man

NON-ELECTRONIC WEIGHT IMPACTS:

(a) COMPONENT	(b) W (tons)	(c) VCG (ft)	(d) MWF_W (tons/ton)	(e) I_W (tons)
. Generator set minus foundation	4.55	-16	1.40	6.37
. Batteries and charger	0.28	-18	1.38	0.39
. Fuel service tank	0.36	-14	1.42	0.51
			(f)	ΣI_W = 7.27

(a) Component name.

(b) W is the weight, in tons, of the component.

(c) VCG is the vertical center of gravity, in feet, above (+) or below (-) the main deck at mid-length.

(d) MWF_W is the marginal weight factor for weight, in tons per ton, for the component. MWF_W depends on the VCG of the component and is found by linear interpolation between the known MWF_W's.

(e) I_W is the ship weight impact, in tons, of the component weight. $I_W = W \times MWF_W$.

(f) ΣI_W is the sum of the component I_W's.

NON-ELECTRONIC SPACE REQUIREMENT IMPACTS:

COMPONENT	(g) S (ft^2)	(h) MWF_S ($tons/ft^2$)	(i) I_S (tons)
1. Generator set, batteries and charger, fuel service tank	266	0.0608	16.17
2. Exhaust penetration through deck above gen. comp't.	4	0.0608	0.24

(j) $\Sigma I_S = 16.42$

(g) S is the space requirement, in square feet, of the component.

(h) MWF_S is the marginal weight factor for space, in tons per square foot.

(i) I_S is the ship weight impact, in tons, of the component space. $I_S = S \times MWF_S$

(j) ΣI_S is the sum of the component I_S's.

NON-ELECTRONIC ELECTRICAL REQUIREMENT IMPACTS:

COMPONENT	$E^{(k)}$ (KW)	$MWF_E^{(l)}$ (tons/KW)	$I_E^{(m)}$ (tons)
1. Generator set	0	0.096	0
		(n)	$\Sigma I_E =$ 0

(k) E is the functional electrical load requirement, in kilowatts, of the component.

(l) MWF_E is the marginal weight factor for electrical requirements, in tons per kilowatt.

(m) I_E is the ship weight impact, in tons, of the component electrical requirements. $I_E = E \times MWF_E$.

(n) ΣI_E is the sum of the component I_E's

NON-ELECTRONIC MANNING REQUIREMENTS IMPACTS:

COMPONENT	(o) M (men)	(p) MWF_M (tons/man)	(q) I_M (tons)
1. Generator set	0	5.7	0
		(r)	$\Sigma I_M =$ 0

(o) M is the manning requirement, in number of men, of the component.

(p) MWF_M is the marginal weight factor for manning, in tons per man.

(q) I_M is the ship weight impact, in tons, of the component manning requirements. $I_M = M \times MWF_M$.

(r) ΣI_M is the sum of the component I_M's.

TOTAL NON-ELECTRONIC IMPACT:

ΣI_W	7.27
ΣI_S	16.42
ΣI_E	0.0
ΣI_M	0.0
(s) I_{TOT} =	23.69

(s) I_{TOT} is the total ship weight impact, in tons, of the equipment and is found by summing ΣI_W through ΣI_M.

EXAMPLE C: GUIDED MISSILE FIRE CONTROL SYSTEM

In this example the ship weight impact of adding a guided missile fire control system (GMFCS) to the baseline frigate is found. This example demonstrates the method of handling electronics equipments and the use of the worksheets for electronics equipments. It will be assumed that no manufacturer's information as to required compartment sizes is given in order to demonstrate the use of the "space utilization factor" derived in Chapter III.

The GMFCS is composed of a radar subsystem, including the radar control console, a computer subsystem, and a firing officer's console. The sizes and weights of the different components are shown in the table below. The director is located topside, with the radar room group located directly below the director in an enclosed compartment. The radar control console and the firing officer's console may be located in the Combat Information Center (CIC) or the Weapons Control Station. The computer group may be located as convenient.

COMPONENT	WEIGHT (LBS)	DIMENSIONS (INCHES) WIDTH	HEIGHT	DEPTH
DIRECTOR	1800	120 D	64	
RADAR RM GROUP				
Transmitter	1800	72	72	36
Cooling Unit	700	36	72	24
Radar Target Data Processor	600	24	72	28
Director Controller	600	24	72	24
	3700			
DISPLAY GROUP				
Firing Officer's Console	500	34	45.5	40
Radar Control Console	500	34	60	40
	1000			
COMPUTER GROUP				
Computer	350	48	72	24
Aid	850	25	72	36
	1200			

The GMFCS requires a total of 40KW of $60H_z$ connected electrical power including the requirements of the cooling unit which is part of the radar room group. Normally the cooling requirements are not included in the values of the equipment support parameters W, S, E, and M, but in this case the equipment includes its own dedicated cooling system located in the equipment compartment so the weight, space, electrical, and manning requirements of this component of the equipment must be counted.

The operational manning requirements for the GMFCS are given by the manufacturer as 3 men.

Impact of GMFCS Weights:

From the information above, and from the engineer's proposals as to the locations of the director, radar room group, and computer group, and a knowledge of the approximate height of the baseline ship's CIC or Weapons Control Station, the weights, W, vertical centers of gravity relative to the main deck at mid-length, VCG, and MWF_W's are found for the different components of the GMFCS. These values are recorded in Columns (b), (c) and (d), respectively, on the worksheet. The component MWF_W's are found by linear interpolation between the known MWF_W's depending on the component VCG. The component weights and MWF_W's are then multiplied to get the component weight impacts, I_W's, which are recorded in Column (e) and summed to find the total ship weight impact, ΣI_W, of the GMFCS weights.

$\Sigma I_W = 6.01$.

Impact of GMFCS Space:

Since in this example it is assumed that no manufacturer's recommendations for internal compartment sizes are given, and that the engineer has no knowledge of an existing similar installation and has not made an arrangement drawing, some method must be used to estimate the internal space requirements of the GMFCS. The method which will be used is to add the actual areas (length x width) of all internal components and multiply the total by the "space

utilization factor" of 2.5. The origin of this factor is explained in Chapter III.

Although it does not occur in this example, the reader must keep in mind that the area of any component which requires compartment space on more than one deck must receive a space allocation for each deck occupied.

From the information in the table above, the areas of the different components are found as follows:

COMPONENT	AREA (ft^2)
1. Radar Room Group	32.7
2. Display Group	18.9
3. Computer Group	14.3
TOTAL =	65.9

The total of the component areas is multiplied by the space utilization factor of 2.5 to get a total compartment space requirement of 165 square feet. This is the value to be used for S and is recorded in Column (g) of the worksheet. For electronics equipments the space allocation must be augmented by a factor of 1.07 as explained in Chapter IV. S_M is this "modified" value of S ($S_M = 1.07 \times S$) and is recorded in Column (h). The MWF_S is recorded in Column (i) and is multiplied by S_M to find the component space impact, I_S, on ship weight. The I_S's are recorded in Column (j) and summed to find the total ship weight impact, ΣI_S, of the equipment

space requirements. In this example no summation is actually made because the overall space requirements of the components have already been lumped together. $\Sigma I_S = 10.73$.

<u>Impact of GMFCS Electrical Requirements</u>:

The total connected load of the GMFCS, including the cooling system, is given as 40 KW. This requirement must be multiplied by an operational load factor to find the functional load of the system. A typical load factor for a GMFCS of this type might be .7 so the functional load becomes 28KW, the value to be assigned to E and recorded in Column (l) of the worksheet. As explained in Chapter IV, the electrical requirements of electronics equipments are multiplied by a factor of 3.0 to get a "modified" electrical requirement. This "modified" requirement is E_M and is recorded in Column (m) of the worksheet. Next, MWF_E is recorded in Column (n) and multiplied by E_M to find the ship weight impacts, I_E's, of the component electrical requirements, Column (o). These I_E's are then summed to find the total ship weight impact, ΣI_E, of the equipment electrical requirements. Again, in this example no summation is actually necessary. $\Sigma I_E = 8.06$.

<u>Impact of GMFCS Manning Requirements</u>:

The stated operational manning requirement for the GMFCS is three men. Reference to the MDM confirms this as

the Condition I operational requirement, but also shows that in Condition III a total of six skilled men is required. As discussed in Chapter III, the number of men required during the condition of readiness that has the largest manning requirement is the number to be used as the equipment's actual requirement. Considering that all six of the men required in Condition III must be skilled, no cross-utilization is assumed to be possible. Since the required number of men for the equipment is five or above, an additional man must be assumed to be necessary on the ship for personnel support functions and the total of additional crew due to the GMFCS installation becomes seven men.

Note: As was the case in Example A, the engineer in this example might want to present a range of impacts in his final analysis assuming different levels of personnel cross-utilization.

The seven-man manning requirement is recorded as M in Column (q) of the worksheet and multiplied by MWF_M (Column (r)) to find the ship weight impact, I_M, of the component manning requirements. The I_M's are recorded in Column (s) and summed to find the total ship weight impact, ΣI_M, of the equipment's manning requirements. Again, no summation is required in this example. $\Sigma I_M = 39.90$.

Total Impact of GMFCS:

Finally, the total ship weight impact, I_{TOT}, of adding the GMFCS to the baseline ship is found by adding ΣI_W, ΣI_S, ΣI_E, and ΣI_M. The full load displacement of the baseline frigate will increase by 64.70 tons as a result of adding the GMFCS.

WORK SHEETS FOR ELECTRONIC ITEMS

EQUIPMENT: EXAMPLE C: GMFCS

BASELINE SHIP: FRIGATE

MWF_W = 1.36 tons/ton 20 feet below main deck at mid-length

1.57 tons/ton at main deck at mid-length

1.94 tons/ton 40 feet above main deck at mid-length

MWF_S = 0.0608 tons/ft^2 MWF_E = 0.096 tons/KW MWF_M = 5.7 tons/man

ELECTRONIC WEIGHT IMPACTS:

(a) COMPONENT	(b) W (tons)	(c) VCG (ft)	(d) MWF_W (tons/ton)	(e) I_W (tons)
1. Director	0.80	+35	1.89	1.51
2. Radar RM Group	1.65	+22	1.77	2.92
3. Display Group	0.45	+16	1.72	0.77
4. Computer Group	0.54	-8	1.49	0.80
			(f)	ΣI_W = 6.01

(a) Component name.

(b) W is the weight, in tons, of the component.

(c) VCG is the vertical center of gravity, in feet, above (+) or below (-) the main deck at mid-length.

(d) MWF_W is the marginal weight factor for weight, in tons per ton, for the component. MWF_W depends on the VCG of the component and is found by linear interpolation between the known MWF_W's.

(e) I_W is the ship weight impact, in tons, of the component weight. $I_W = W \times MWF_W$

(f) ΣI_W is the sum of the component I_W's

ELECTRONIC SPACE REQUIREMENT IMPACTS:

COMPONENT	(g) S (ft^2)	(h) S_M (ft^2)	(i) MWF_S ($tons/ft^2$)	(j) I_S (tons)
1. GMFCS	165	176.6	0.0608	10.73
			(k)	$\Sigma I_S = 10.73$

(g) S is the space requirement, in square feet, of the component.

(h) S_M is the modified space requirement of the component. $S_M = 1.07 \times S$.

(i) MWF_S is the marginal weight factor for space, in tons per square foot.

(j) I_S is the ship weight impact, in tons, of the component space. $I_S = S_M \times MWF_S$

(k) ΣI_S is the sum of the component I_S's.

ELECTRONIC ELECTRICAL REQUIREMENT IMPACTS:

COMPONENT	(l) E (KW)	(m) E_M (KW)	(n) MWF_E (tons/KW)	(o) I_E (tons)
1. GMFCS (incl. cooling)	28	84	0.096	8.06
			(p)	ΣI_E = 8.06

(l) E is the functional electrical load requirement, in kilowatts, of the component.

(m) E_M is the modified electrical requirement of the component. $E_M = 3 \times E$.

(n) MWF_E is the marginal weight factor for electrical requirements, in tons per kilowatt.

(o) I_E is the ship weight impact, in tons, of the component electrical requirements. $I_E = E_M \times MWF_E$

(p) ΣI_E is the sum of the component I_E's.

ELECTRONIC MANNING REQUIREMENT IMPACTS:

COMPONENT	(q) M (men)	(r) MWF_M (tons/man)	(s) I_M (tons)
1. GMFCS	7	5.7	39.90
		(t)	ΣI_M = 39.90

(q) M is the manning requirement, in number of men, of the component.

(r) MWF_M is the marginal weight factor for manning, in tons per man.

(s) I_M is the ship weight impact, in tons, of the component manning requirements. $I_M = M \times MWF_M$.

(t) ΣI_M is the sum of the component I_M's.

ELECTRONIC TOTAL IMPACT:

ΣI_W	6.01
ΣI_S	10.73
ΣI_E	8.06
ΣI_M	39.90
(u) I_{TOT}	=64.70

(u) I_{TOT} is the total ship weight impact, in tons, of the equipment and is found by summing ΣI_W through ΣI_M.

EXAMPLE D: SEARCH RADAR SET

In this example the ship weight impact of adding a radar set to the baseline ship is found. As in Example C, the method of handling electronics equipments is demonstrated. This example also demonstrates that normal cooling services from the installed ship service air conditioning system are not considered in using MWF's.

The radar set consists of an antenna and pedestal, radar set control, radar receiver, radar transmitter, tuned cavity and a microwave components assembly.

The weight of the external equipment (antenna and pedestal) is 195 pounds and the weight of the below-decks equipment is 920 pounds. The manufacturer recommends that all below-decks equipment be installed in a single 8' x 12' compartment. The set is designed to operate with a standard Navy indicator and the radar set control unit should be bulkhead mounted adjacent to the indicator. The weight of the indicator is estimated to be 200 pounds and the weight of the radar set control unit is 16 pounds. The indicator and radar set control unit will require 5 square feet of deck space on the bridge.

The radar set and indicator require 25 amps of 115V, 60H_z, single phase electricity and will require dissipation of 2.7KW of heat by the ship service air conditioning system.

The Condition I operational personnel requirements of the radar set consist of one operator at the remote control/indicator position.

Impact of Radar Set Weights:

From the information above, and from the engineer's proposals as to the locations of the antenna and below-decks equipment and a knowledge of the approximate height of the baseline ship's bridge, the weights (W), vertical centers of gravity with respect to the main deck at mid-length, and MWF_W's are found for the different components of the radar set. The MWF_W's are found by linear interpolation between the given MWF_W's. The weights and MWF_W's are then multiplied, and their products summed to find the ship weight impacts, ΣI_W, of the radar set component weights (see worksheets). $\Sigma I_W = 0.97$.

Impact of Radar Set Space:

The space requirements of the below-decks compartment and the space on the bridge for the indicator and radar set control unit are added to get a total space requirement, S, of 101 square feet. S_M is then found by multiplying S by 1.07, and the component space impacts, I_S's, are found by multiplying the S_M's by MWF_S. The I_S's are summed to get the total ship weight impact, ΣI_S, of the radar set. $\Sigma I_S = 6.57$.

<u>Impact of Radar Set Electrical Requirements</u>:

In order to find the KW requirement for the radar set from the information given, the voltage is multiplied by the amperage and the power factor (0.8 in this case) and then divided by 1000 to convert from watts to kilowatts.

(115V x 25A x .8)/1000 = 2.3KW

This is the connected electrical requirement of the radar set. The requirement for heat dissipation is not included in the radar set's specific electrical requirement because it is considered to be of "normal" magnitude and will not require a dedicated cooling system for this radar only. This rationale is explained in Chapter III. The 2.3KW requirement is multiplied by the operational load factor deemed most applicable to the radar set. A typical operational load factor for a radar set is 0.7. Multiplying the 2.3KW requirement by 0.7 yields a functional load of 1.6KW. This is the value assigned to E. In an actual case, an electrical requirement this small would probably be ignored, but the calculations will be carried on here for demonstration purposes. The value of E is multiplied by 3.0 to find E_M (since the radar set is an electronics equipment) and E_M is in turn multiplied by MWF_E to find the ship weight impact, I_E, of the component electrical requirements. The I_E's would be summed to find the total ship weight impact, ΣI_E, of the radar system components'

electrical requirements but in this example no summation is necessary because all component requirements have been lumped together on the worksheet. $\Sigma I_E = 0.46$.

Impact of Radar Set Manning Requirements:

The stated Condition I operational manning requirement of the radar set is one skilled operator at the remote control/indicator position on the bridge. Reference to the MDM shows that the Condition III maintenance requirement for this radar is 0.4 man with no full-time operator required. (In other words, there is no need to have a man assigned to the radar during each Condition III watch section.) The Condition I manning requirement is the larger of the two requirements and is therefore the controlling requirement. No cross-utilization is assumed because the one operator is required to be skilled. The value assigned to M is 1 and this value is multiplied by MWF_M to find the ship weight impact, ΣI_M, of the radar set manning requirement. Again, no summation is actually necessary in this example. $\Sigma I_M = 5.70$.

Total Impact of Radar Set:

Finally, the total ship weight impact, I_{TOT}, of adding the radar set to the baseline ship is found by adding ΣI_W, ΣI_S, ΣI_E, and ΣI_M (see worksheet). The full load displacement of the baseline ship in this example will increase by 13.70 tons as a result of adding the radar set.

WORK SHEETS FOR ELECTRONIC ITEMS

EQUIPMENT: EXAMPLE D: RADAR SET

BASELINE SHIP: FRIGATE

MWF_W = 1.36 tons/ton 20 feet below main deck at mid-length

1.57 tons/ton at main deck at mid-length

1.94 tons/ton 40 feet above main deck at mid-length

MWF_S = 0.0608 tons/ft^2 MWF_E=0.096 tons/KW MWF_M=5.7 tons/man

ELECTRONIC WEIGHT IMPACTS:

(a) COMPONENT	(b) W (tons)	(c) VCG (ft)	(d) MWF_W (tons/ton)	(e) I_W (tons)
1. Antenna and pedestal	0.09	+35	1.89	0.17
2. Indicator and radar set control	0.10	+22	1.77	0.18
3. Below-decks equipment	0.41	-6	1.51	0.62
			(f)	ΣI_W = 0.97

(a) Component name.

(b) W is the weight, in tons, of the component.

(c) VCG is the vertical center of gravity, in feet, above (+) or below (-) the main deck at mid-length.

(d) MWF_W is the marginal weight factor for weight, in tons per ton, for the component. MWF_W depends on the VCG of the component and is found by linear interpolation between the known MWF_W's.

(e) I_W is the ship weight impact, in tons, of the component weight. $I_W = W \times MWF_W$

(f) ΣI_W is the sum of the component I_W's

ELECTRONIC SPACE REQUIREMENT IMPACTS:

COMPONENT	(g) S (ft^2)	(h) S_M (ft^2)	(i) MWF_S ($tons/ft^2$)	(j) I_S(tons)
1. Indicator radar set control and below-decks equipment	101	108.1	0.0608	6.57
			(k)	ΣI_S = 6.57

(g) S is the space requirement, in square feet, of the component.

(h) S_M is the modified space requirement of the component. $S_M = 1.07 \times S$.

(i) MWF_S is the marginal weight factor for space, in tons per square foot.

(j) I_S is the ship weight impact, in tons, of the component space. $I_S = S_M \times MWF_S$

(k) ΣI_S is the sum of the component I_S's.

ELECTRONIC ELECTRICAL REQUIREMENT IMPACTS:

COMPONENT	(l) E (KW)	(m) E_M (KW)	(n) MWF_E(tons/KW)	(o) I_E(tons)
1. Radar set	1.6	4.8	0.096	0.46
			(p)	ΣI_E = 0.46

(l) E is the functional electrical load requirement, in kilowatts, of the component.

(m) E_M is the modified electrical requirement of the component. $E_M = 3 \times E$.

(n) MWF_E is the marginal weight factor for electrical requirements, in tons per kilowatt.

(o) I_E is the ship weight impact, in tons, of the component electrical requirements. $I_E = E_M \times MWF_E$

(p) ΣI_E is the sum of the component I_E's.

ELECTRONIC MANNING REQUIREMENT IMPACTS:

COMPONENT	(q) M (men)	(r) MWF_M (tons/man)	(s) I_M (tons)
1. Radar set	1	5.70	5.70
		(t)	ΣI_M = 5.70

(q) M is the manning requirement, in number of men, of the component.

(r) MWF_M is the marginal weight factor for manning, in tons per man.

(s) I_M is the ship weight impact, in tons, of the component manning requirements. $I_M = M \times MWF_M$.

(t) ΣI_M is the sum of the component I_M's.

ELECTRONIC TOTAL IMPACT:

ΣI_W	0.97
ΣI_S	6.57
ΣI_E	0.46
ΣI_M	5.70
(u)	$I_{TOT} = 13.70$

(u) I_{TOT} is the total ship weight impact, in tons, of the equipment and is found by summing ΣI_W through ΣI_M.

Thesis
B82915 Bryant 165481
Use of marginal
cost factors by ship
designers and component designers.